FLEXIBLE PAVEMENT
STRUCTURAL SECTION
DESIGN GUIDE
FOR
CALIFORNIA CITIES AND COUNTIES

68-64

68-64

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FOREWORD

This booklet is intended to provide a concise and useful tool to the designer of city streets and county roads.

The concepts and methods used herein are not new. The guide is based on the results of extensive studies, tests and numerous reports by various agencies concerning the many factors affecting the structural design of roadway sections.

This guide should prove quite helpful to many cities and counties irrespective of the amount or lack of laboratory facilities and testing equipment.

Suggestions for improvements to this guide may be directed to either the County Engineers Association of California or the League of California Cities.

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INTRODUCTION

The earth's crust, in its many variations, remains as the foundation and source of materials for all present-day roadways. Traffic and weather are the major forces tending to destroy the roadway, forces that the highway engineer must account for and accommodate, both in construction of the roadway, and throughout its life. His real problem is not to merely succeed in this accommodation, but to do so at least cost.

The modern roadway is designed, among other things, to minimize the undulations of the earth's surface. As a practical matter, one critical element in such design is the highway embankment. Economy usually dictates that the materials for constructing embankments be taken from roadway excavations. Most materials which are taken from roadway excavations and placed in embankments can neither support modern wheel loads nor provide an adequate, all-weather surface. Therefore, a man-made surfacing of imported materials must be constructed over these basement soils.

Structural design of the roadbed is the determination of the thickness of subbase, base and pavement to be placed over the basement soil. Basic to the problem is the selection of the most suitable available materials and their most advantageous use. Their grouping in horizontal layers under the pavement should be such that the most benefit will be derived from the inherent qualities of each material.

A pavement may be designed to support any traffic density and axle load. It does this by distributing downward and outward the high-intensity stresses imposed by a loaded wheel, reducing these stresses in magnitude until they may be safely carried by the basement soil. The pavement structure is made up of materials of successively higher load-carrying capacity from basement soil to pavement surface. In establishing the depth of each layer, the objective is to provide a minimum thickness of overlying material that will reduce the unit stress on the next lower layer, commensurate with the load-carrying capacity of the material comprising that layer.

The purpose of this guide is to provide acceptable criteria and methods upon which design of the structural section can be based. The material is slanted towards engineers who need to design roads and streets with standards oriented toward the requirements of the cities and counties rather than the more heavily traveled State highways.

The methods and procedures are not new in concept or theory. They are, however, representative of the thinking of the California Division of Highways, the County Engineer's Association of California, the League of California Cities, and other equally interested groups. This guide is based on the results of extensive studies and tests and on numerous reports by various agencies concerning the multitude of factors affecting the structural design of roadway sections.

SCOPE AND LIMITATIONS

The structural design of flexible pavements is not an exact science and, therefore, it is not possible to formulate one set of design criteria that could meet the requirements of every road everywhere. Traffic conditions, climate and geology, materials of construction, and of course, economics, are the variables that demand from the engineer the fullest application of his professional judgment and engineering skills.

For some time the State of California has been using a structural design formula based on empirical relationships developed from several test tracks and the performance of pavements in actual service. The original formula has been modified as more and better information has become available, and will be modified in the future as continuing research contributes further information.

The basic methods for structural design presented in this guide are based on this formula. Definitions of terms are provided and separate variables in the formula are discussed in detail. Several approaches for approximating the values of the variables are presented. These approaches represent degrees of refinement and are geared to the experience of the engineer.

The guide does not cover design of those facilities with a Traffic Index of 8 or more based on a 10 year design life. It is felt that this magnitude of traffic requires the same criteria used for State highways. Design of structural sections for these highways is adequately covered in manuals (1, 2) published by the California Division of Highways.

THE STRUCTURAL SECTION AND ITS COMPONENTS - DEFINITIONS AND USES

Flexible Pavement - Pavement having sufficiently low bending resistance to maintain intimate contact with the underlying structure yet having the required stability to support the traffic loads; e.g., macadam, crushed stone, gravel, and all bituminous types not supported on a rigid base.

Surface Course - The top layer of a pavement, designed to provide structural value and a surface resistant to traffic abrasion. It should help protect the lower layers in the pavement structure from extreme climatic effects and should be dust-free and skid-resistant.

Base Course - The layer of a two or more course pavement placed directly under the surface course. It is characterized by good load distribution qualities (high interparticle friction).

Asphalt Concrete (AC) - Used primarily as a surface course and in some instances as a base course. Paving asphalts are normally specified for this material and crushed rock or aggregate with high interparticle friction is desirable.

Road-Mixed Asphalt Surfacing - Normally called for when facilities for making asphalt concrete (AC) are not economically available. Liquid asphalts are normally used and the aggregate tends to be variable. It is used on low traffic volume roads where higher types of surfacing are not necessary for traffic service.

Bituminous Seal-Coat - A bituminous coating with or without aggregate applied to the surface of a pavement for the purpose of waterproofing and preserving the surface, relivening a previous bituminous surface, altering the surface texture of the pavement, or providing resistance to traffic abrasion. They are also suitable for delineating shoulders where the entire roadbed is to be surfaced with bituminous material and a contrast with the traveled way is desirable. Seal coats may also provide a light-wearing surface and fill shrinkage cracks in the pavement.

Penetration Treatment - This treatment consists of the application of light liquid asphalt to roadbed material. It is used principally as a dust palliative on detours, medians, and parking areas. It is also used for erosion control on cut and fill slopes.

Tack Coat - (Paint Binder) - The initial application of bituminous material to an existing surface to insure bond between the superimposed construction and the old surface. Usually consists of an asphaltic emulsion, although paving asphalt is sometimes used.

Prime Coat - The initial application of a low viscosity liquid bituminous material to an absorbent surface, preparatory to any subsequent treatment, for the purpose of hardening or toughening the surface and promoting adhesion between it and the superimposed construction. Usually consists of liquid asphalt.

Cement Treated Base (CTB) - A base layer constructed with good quality well-graded aggregate mixed with up to 6% cement. CTB provides a high slab strength allowing the imposed load to be spread over a large area. Class "A" CTB is expected to have a minimum compressive strength of 750 psi in seven days. Class "B" CTB is expected to reach 400 psi in seven days. Both Class "A" and Class "B" CTB are used under asphalt concrete to provide added strength on the heavier traveled roads. The difference between these two classes is in the amount of cement used in the mixture.

Class "C" CTB does not provide for a strength requirement, but is used primarily to increase the "R"-value of a material so as to make it suitable for use as a base course under a bituminous surface.

Class "D" CTB provides for the upgrading of in-place materials for their use in the base course. It also has some application in improving the quality of subbase materials.

Lime Stabilized Materials - Lime is primarily used to treat clayey materials in the structural section. Response is normally poor when used with granular materials. Application is usually made in the basement soil or subbase layer although the use of lime stabilized material in the base course has been successful on lightly traveled roads.

Untreated Aggregate Base - High quality mineral aggregate used only in flexible pavement construction. It normally requires some processing to upgrade quality.

Subbase - One or more courses of soil or aggregate or both, of planned thickness and quality, placed on the subgrade as a foundation for a base. Used where the basement soil will not support a structural section consisting of pavement and base alone, or where it is more economical to reduce the base thickness requirement by introducing this lower-priced layer.

Imported Borrow - In terms of structural design, this material would fall under basement soil, below. It is for embankment brought in from a source outside the project right-of-way. Quality is sometimes specified in the project special provisions.

Basement Soil - The material in excavations, embankments, and embankment foundations immediately below the first layer of subbase, base, or pavement, and to such depth as may affect structural design.

Subgrade - The portion of the roadbed surface which has been prepared, as specified, and upon which a layer of specified roadbed material, base, or surfacing is to be placed.

R-VALUE DESIGN METHOD

This method considers three variables in order to arrive at the necessary structural section thickness.

Traffic - The first of these variables, exerts a destructive effect upon a road proportional to the weight of the loaded trucks and their frequency.

Slab Strength - The slab strength of the layers of the pavement structure, acts to spread out the load imposed by the traffic and to distribute it to the underlying layer or layers. This slab strength constitutes the second variable.

Resistance Value - The ability of the underlying layers to resist being deformed laterally or "squeezed out" by the distributed load is the third variable and is termed the resistance value.

TRAFFIC EVALUATION

Relationships between the weight of a loaded axle and the thickness of pavement needed to support this axle have been determined experimentally (1). Also, the relationship between repetition of loads and pavement thickness has been explored. The interaction between load weight, number of repetitions, and pavement thickness was expressed mathematically and provides a basis for converting the many different wheel loads on the road to a common denominator. This common denominator is the 5,000 pound equivalent wheel load (EWL). The destructive effect of one passage of a given truck wheel is expressed as an equivalent number of passages of 5,000 pound wheel loads.

Estimation of the total number of EWL's on a section of road for a given period of time has been simplified by the use of truck constants. A truck constant is a number which represents the total number of 5,000 pound wheel loads which would be generated in one year by the passage of one truck per day in one direction. This truck is assumed to be carrying an average load which has been determined through statistical treatment of axle weight and frequency data. Each axle classification (e.g., 2-axle, 3-axle, etc.) has a separate truck constant. A method for calculating truck constants is shown in Appendix A.

If very accurate truck constants are desired, they should be calculated for the highway under consideration (3). Because of the cost, this would normally be done only for special situations where the engineer feels the traffic is unique and he needs the information to effect a savings or justify a heavier section. For the typical situation, the constants listed in Table A-5 of Appendix A may be used. These constants represent the results of statewide loadmeter analyses. Most engineers using this manual will be concerned only with the second column of constants entitled "City Streets and County Roads" which were recently developed (3). The first column would be used in the design of roads and streets with a T.I. of 8 or more.

To evaluate the destructive effect of traffic for a given project, the total number of EWL's expected on the road during its design life is estimated by using truck constants in conjunction with average daily truck traffic (ADTT) data from classified traffic counts. The data are expanded separately for each axle classification according to the engineer's estimate of the increase or decrease in truck traffic volume expected during the life of the facility. In this respect, the area master plan should be perused and a consultation held with the planning office. This total anticipated EWL is then converted by formula (Table A-1 in Appendix A), to Traffic Index (T.I.). The Traffic Index is a convenient number to use in designing structural sections as it bears a direct relationship to the thickness of pavement required. Appendix A presents the T.I. calculation in a step by step manner.

The design period or life of a pavement would not normally be less than 10 years. When traffic volume approaches that of a State highway, a 20-year design life should be used. Shorter periods are used when the pavement is only temporary construction or when it is planned to replace the highway prior to the end of the normal design life.

METHODS FOR OBTAINING TRAFFIC INDEX

The standard method of traffic evaluation provides the most accurate data and should be used whenever possible. This method calls for:

1. Truck constants, either those developed especially for the project or those listed in this text. (Table A-5, Appendix A).

2. A truck traffic count showing truck volume classified according to number of axles per truck and presented as Average Daily Truck Traffic.

3. Factors to estimate increase or decrease in traffic volume during design life of pavement.

4. Design life of pavement.

Procedure for calculation of T.I. according to this method is found both in Appendix A and in a shortened version in Test Method No. Calif. 301. In general, a T.I. less than 4 should not be used.

Estimation of T.I. by ADT and Percentage of Trucks

A somewhat less sophisticated and less accurate method of estimating the traffic index is the subject of the graph shown in Figure 1. To estimate T.I. by this method, the engineer needs:

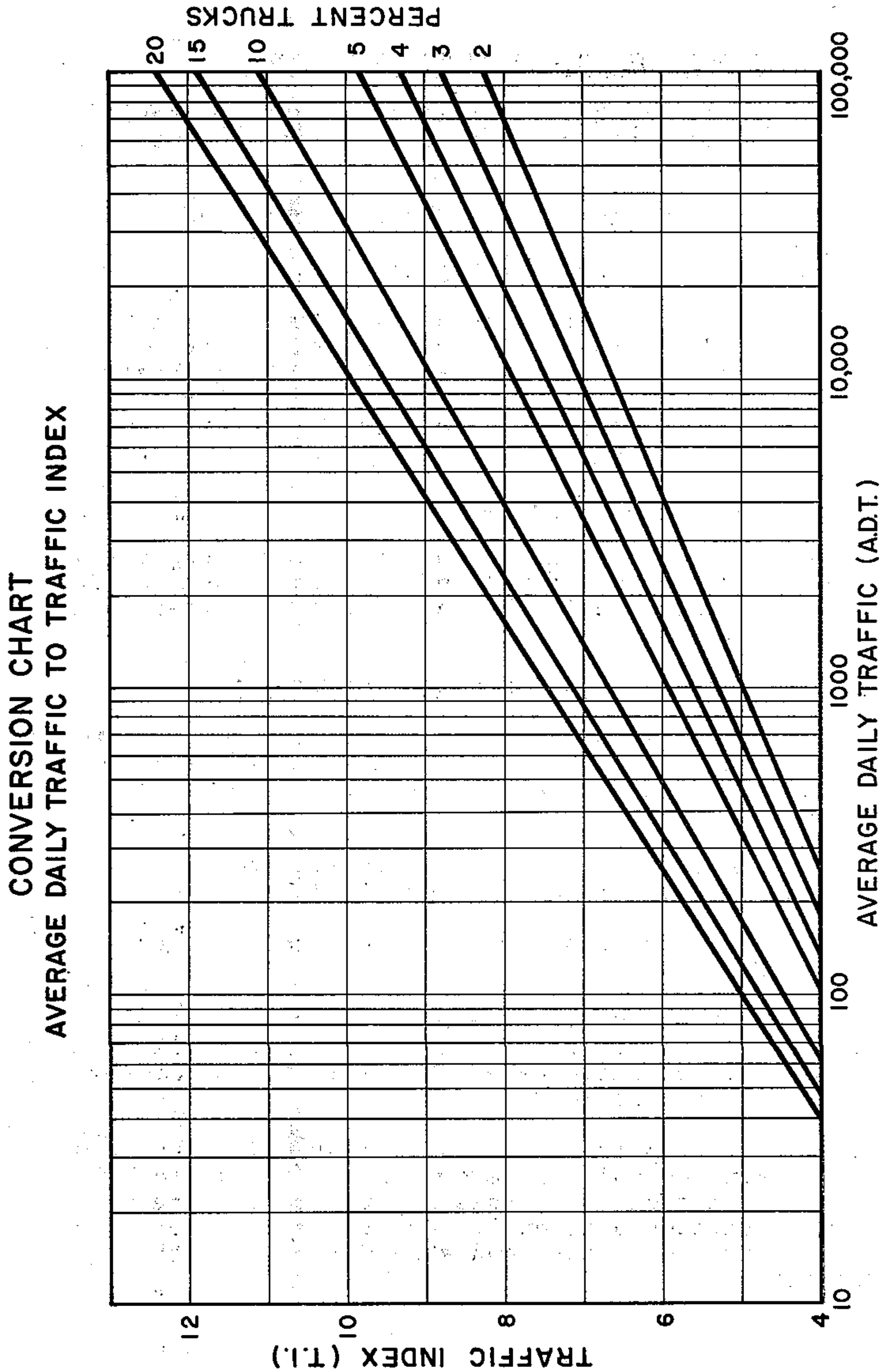
1. A number representing the average daily traffic (ADT) for the proposed facility.

2. A number showing trucks as a percentage of the ADT.

3. Some idea as to the expected increase in ADT during the design life of the project as well as an idea of anticipated change in the percentage of trucks using the road.

The first step in the estimation of a T.I. by this method is to obtain the ADT and percentage of trucks for the facility. On an existing road, this may be easily done by relatively inexperienced personnel. Counts may be made on a 24-hour basis or by spot checks and should include both directions of traffic.

Figure 1


CONVERSION CHART
AVERAGE DAILY TRAFFIC TO TRAFFIC INDEX
PERCENT TRUCKS
20
15
10
5
4
3
2
100,000
10,000
1000
100
10
AVERAGE DAILY TRAFFIC (A.D.T.)
12
10
8
6
4
TRAFFIC INDEX (T.I.)

Vehicles to be counted as trucks include buses and 2-axle vehicles with dual rear tires as well as the larger trucks. Pickups, panel trucks and cars with trailers are not classed as trucks.

The ADT and percentage of trucks should next be modified to represent the average condition for the design period. If the opening ADT is 1,000 and the anticipated ADT at the end of the design period is 1,400, the chart should be entered with an ADT of 1,200. The same holds true for truck percentage.

The ADT/T.I. chart is based upon a 10-year design life. Data for the chart was taken from the 1963 classified vehicle census and developed using the constants for city streets and county roads shown in this text.

Estimation of T.I. According to Road Type

In the absence of more detailed knowledge, traffic may be estimated by considering the type of facility to be designed. Estimates of traffic made in this manner tend to be inaccurate and, for this reason, should allow for a safety factor. The estimated Traffic Index should be justified by a description of the facility, the area it serves, and the normal types of traffic carried. The table below lists several road categories and the T.I. which might be expected to correspond with these categories. The last four categories in the table are difficult to estimate. Since roads in these categories are more critical with regard to repair, due to heavier traffic, the T.I. should be estimated using either the standard method or the chart shown in Figure 1.

TYPE OF FACILITY	T.I.
Minor residential streets and Cul-de-sacs.	4
Average residential streets.	4.5
Residential collectors and minor or secondary collectors.	5
Major or primary collectors providing for traffic movement between minor collectors and major arterials.	6
Farm-to-market roads providing for the movement of traffic through agricultural areas to major arterials.	5 - 7

TYPE OF FACILITY	T.I.
Commercial roads (arterials serving areas which are primarily commercial in nature).	7 - 9
Connector roads (highways and arterials connecting two areas of relatively high population density).	7 - 9
Major city streets and thoroughfares and county highways.	7 - 9
Streets and highways carrying heavy truck traffic. This would include streets in heavily industrialized areas.	9+

For subdivision traffic only, it is permissible to use the chart shown in Figure 2. This chart relates Traffic Index to the number of houses served. It should be emphasized that this chart applies only to residential and residential collector streets. Streets carrying other traffic through the subdivision and streets going by a commercial area should not be analyzed by a house count chart.

Prior to the use of this chart, the engineer should consult with the area planners as to future plans for temporarily dead-ended streets. Many times either commercial developments tie into residential collectors, or the collectors are extended to serve much larger areas.

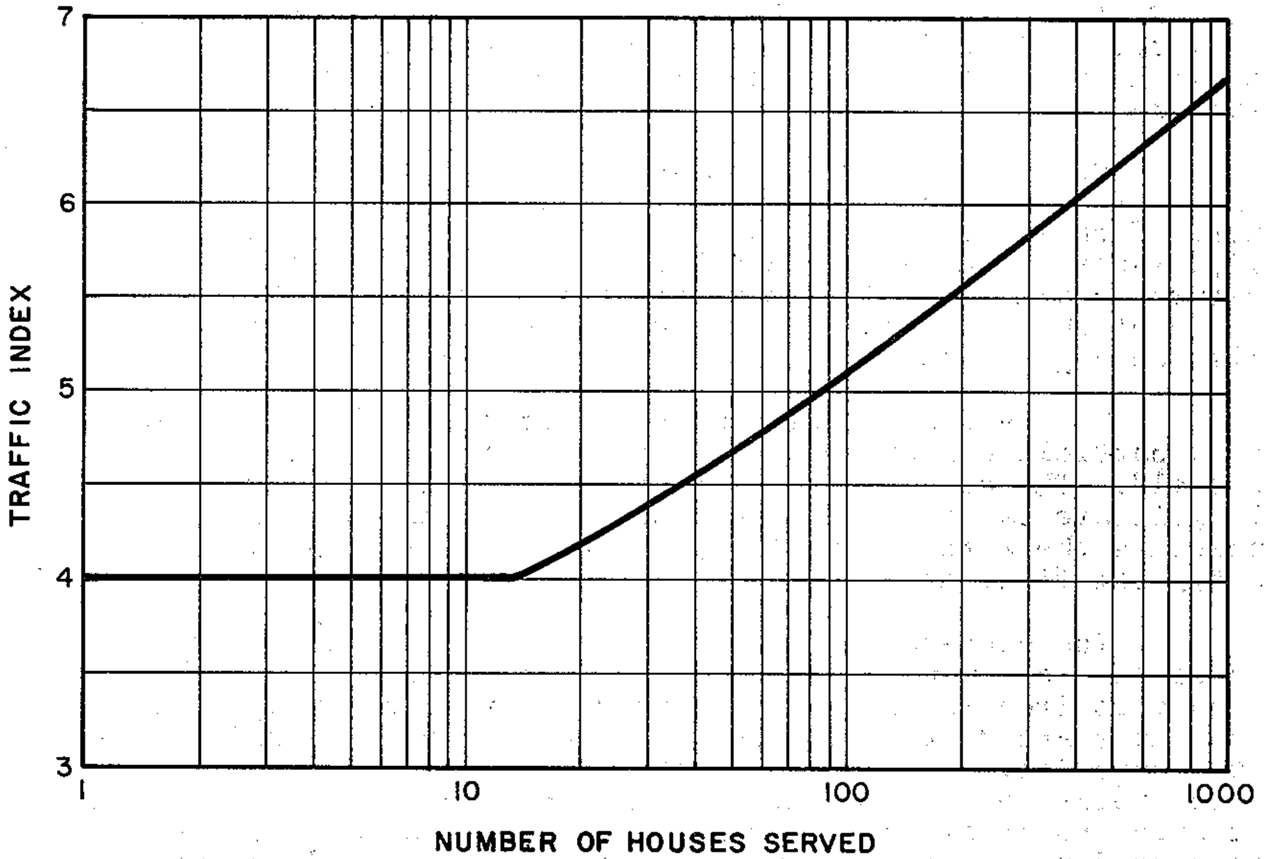
The chart is based upon each residence generating an average eight trips per day. Truck traffic is assumed to be three percent of the subdivision traffic. The truck traffic is assumed to consist, almost exclusively, of 2-axle and 3-axle vehicles. Truck constants of 350 for the 2-axle, 6-tire trucks and 900 for the 3-axle trucks are based upon the common trucks found on these streets. Truck traffic is assumed to consist of 89% 2-axle, 6-tire trucks and 11% 3-axle trucks. Traffic Indices are based upon a ten-year design life for the facility.

Estimation of T.I. in Special Situations

Many times a particular road presents a unique situation which demands that the engineer use a little more judgment to arrive at a truly representative Traffic Index. An example of such a situation might occur where a road serves an agricultural or recreational area and has a heavily used rock quarry at some point along the route. Since the rock trucks would haul one way loaded and one way empty, the engineer could use a different T.I. for each direction of travel and effect significant economy in design.

Figure 2

CHART FOR ESTIMATION OF TRAFFIC INDEX USING A HOUSE COUNT



Notes: For use only within subdivisions for residential and residential collector streets.

Chart is based on a 10-year design life.

Solution of these special problems allows more individual expression and gives the engineer much personal satisfaction.

QUALITY OF SUBGRADE SUPPORT

The term resistance, as used in this guide, refers to the ability of a material to resist lateral deformation when acted upon by a vertical load. When plastic flow occurs, the soil moves out and away from the applied load. This displacement of soil causes a "wave development" on all sides of the load. Resistance to this plastic flow is primarily dependent upon interparticle friction. Interparticle friction is increasingly important in the lower levels of the pavement structure.

Measurement of the resistance or R-value is made by means of the stabilometer test. An index of resistance to plastic flow is arranged on a scale from 0 to 100. Theoretically, water would have an R-value of 0 since it would transmit pressure equally in all directions, while steel would show an R-value of 100 since no measurable deformation would occur. Soils and aggregates will range from less than 5 to about 85.

The R-value is determined using soil specimens which have a particle arrangement closely approximating the soil in the field. The specimens are tested in a state as near to full moisture saturation as possible. Thus, the R-value represents the worst possible state the soil might attain at the typical field density state.

The procedure also takes into account the fact that some soils are expansive. When a compacted soil expands on exposure to free water, the density and particle arrangement of the mass are disrupted causing a lowering of the stability of the material. The expansion, however, may be controlled if the expansive material has a weight of cover over it sufficient to equal the expansion pressure. In the R-value test method the tendency for expansion is considered and the cover thickness determined for the layer being analyzed is not only sufficient to spread out the load and prevent displacement of the layer, but is also heavy enough to neutralize the expansive forces within the layer.

DETERMINATION OF THE R-VALUE

The stabilometer test (Test Method No. Calif. 301) is the standard method for obtaining an R-value. This test method will not be elaborated upon at this point.

If R-value tests have been made in the past on nearby, similar soils, it is sometimes possible to use this information to evaluate the soil in question. To do this, it is necessary to perform simple classification tests on the soil to be evaluated and to compare these results with those obtained on the previously tested nearby soil. If the grain size classification and Atterberg Limits are comparable and if the soil is apparently from the same soil formation, then the probability is high that the R-values will be similar.

Diligence in record keeping will pay dividends if the records help save the cost of extensive R-value testing.

When sampling areas for new construction, it is essential to use good judgment. If the job includes cut and fill work, it would do no good to sample material at the bottom of the fill sections which will be covered with material from an adjacent cut. The material which will form the basement soil for the project is the material to be sampled. Sufficient samples should be taken to establish the quality of the different soils on the job. Design would normally be based on the lowest R-value encountered, unless large areas of good and bad material allowed the designer to economically change the design at intervals. Changes in structural section design will not effect a savings if they are made too often. Sometimes it is economically feasible to take out a short section of low R-value material to allow a design based on the higher R-value soil.

Other information useful at this point might include:

1. Identification of soil types from existing soil maps, aerial photographs, and other sources. Agricultural agencies and geological agencies may be able to contribute much information.

2. Investigation of ground water conditions, especially during severe periods (winter, irrigation, etc.).

3. Examination and sampling, when appropriate, of existing roadway cuts and other excavations.

4. Review of the design and construction of existing roads in the vicinity and their present condition.

5. Discussions with maintenance personnel and others who may have personal knowledge of conditions affecting the design.

Estimation of R-value Using Soil Classification

Rough estimates of R-value can be made using some simple soil classification tests in conjunction with the sand equivalent (SE) test. Each soil type (e.g. sandy clay, etc.) roughly encompasses a certain R-value range. The R-value range for a soil type may be narrowed by knowing more about the soil's plasticity and by knowing its sand equivalent value (Test Method No. Calif. 217).

The following soil classification sheets and triangular chart (Figures 3 and 4) are included as aids. To classify soils on the triangular chart (Figure 4), a sieve analysis and hydrometer analysis are necessary (Test Method Nos. Calif. 201, 202, and 203).

When the soil classification has been determined from Figure 4, the chart in Figure 5 may be used to approximate the R-value. In this chart, the curves representing the various soil types show a stylized approximate frequency distribution of R-values for that particular type soil.

For fine-grained materials, the upper tail or high R-value portion of the curve represents lower plasticity, relative to the soil type, while the lower tail represents soils of the same type having higher plasticity. The sand equivalent values provide additional subdivisions within the chart.

For a particular SE value, chances are very good that the R-value for the same material will be as high or higher than the R-value designated by the corresponding dashed line. The converse, however, is not true since it is possible for a material to have a high R-value with a relatively lower SE.

The curves for coarse-grained materials are affected in the same manner, by the presence of clay, with the lower tail representing materials with either more clay or clay with higher activity. In coarse-grained materials with little or no clay, the lower tail represents hard, smooth-surfaced and poorly graded (well sorted) material while the upper tail represents rough-surfaced and well graded material.

The use of the chart must be tempered with good judgment and it should always be borne in mind that R-values obtained in this manner are estimations only. The reasoning behind these estimations should be fully documented in the materials report to provide the reviewers with as much basic data as possible.

Figure 3

FIELD CLASSIFICATION OF SOILS

Minimum Description Required for Classification of Soil in place as sampled

	PROPERTY		FIELD IDENTIFICATION
1.	MOISTURE		Dry-Moist-Wet-Very Wet (very wet means free water evident)
2.	a. COMPACTNESS coarse grained soils		Loose-Dense-Very dense
	b. CONSISTENCY fine grained soils		Very soft Exudes between fingers when squeezed. Soft Easily molded in fingers. Firm Can be molded by strong pressure in fingers Stiff Cannot be molded in fingers. Hard Brittle or very tough
3.	COLOR		Indicate range of color: e.g. brown to reddish brown. Use qualifying adjective to indicate cast, as reddish, vs.
4.	SOIL TYPES	SIZE	
Coarse grained non-cohesive	Broken rock	+3"	Angular fragments of rock
Coarse grained non-cohesive	Stone Coarse Medium Fine	 -3" + 1" -1" + 3/8" -3/8" + #10	Crushed or naturally angular rock particles
Coarse grained non-cohesive	Boulders	+6"	Rounded fragments of rock
Coarse grained non-cohesive	Cobbles	-6" + 3"	Rounded
Coarse grained non-cohesive	Gravel Coarse Medium Fine	 -3" + 1" -1" + 3/8" -3/8" + #10	Rounded rock particles
Coarse grained non-cohesive	Sand Coarse Fine	 -#10+ #40 -#40 + #200	Particles visible to naked eye. No cohesion when dry.

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Figure 3 (Continued)

4.	SOIL TYPES CONT'D.	SIZE	FIELD IDENTIFICATION
Fine Grained Cohesive Soils	Silts	-#200 + 5 Micron	Particles mostly -200; barely visible to naked eye. Some plasticity, and exhibits marked dilatancy (Shaking test shows quick or "livery" condition.) Dries mod. quickly and can be dusted off the fingers. Dry lumps possess cohesion, but easily powdered in fingers.
	Loams		Contain sand, silt and clay sizes; possess mod. plasticity.
	Sandy Clay		Mod. to high plasticity and dry strength. No dilatancy.
	Silt-Clay		Fine grained (-200). No dilatancy. Appreciable plasticity.
	Clay	-5 Micron	Smooth to touch and plastic, no dilatancy. Sticks to fingers and dries slowly. Shrinks appreciably on drying. Dry lumps can be broken but not powdered. They disintegrate under water. — Lean clays show these properties to low degree. Fat clays show these properties to high degree.
Organic	Peats		Fibrous organic matter, usually brown or black in color. Firm: Fibers compressed together. Spongy: Very compressible and open structure.
5.	PLASTICITY		Non-plastic; slightly plastic; moderately plastic; highly plastic. Inherent property of soil. Moisten as necessary to evaluate plasticity.

Figure 4

SOIL CLASSIFICATION CHART

% CLAY = % finer than 5 microns
% SILT = % passing #200 − % clay
% SAND = % passing # 8 − % passing # 200

If over 50% is retained on # 8.
sample is gravel-modified by amounts
of other constituents contained. (sand, silt, clay)

EXAMPLE CLASSIFICATION
Given: % passing #8 = 100
% passing # 200 = 32
% passing 5 microns = 16

For solution see dashed lines on chart.
Material is silty sand.

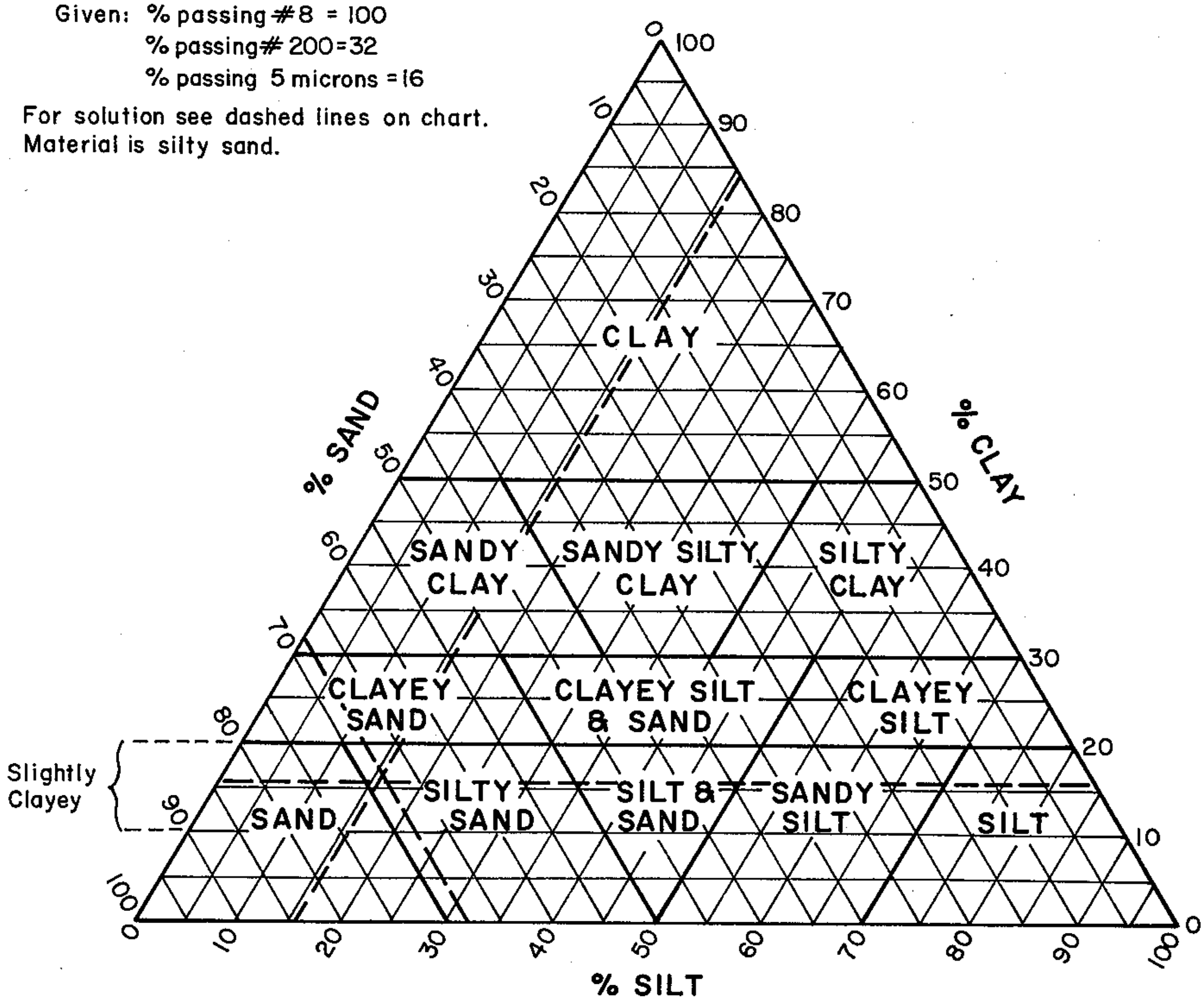
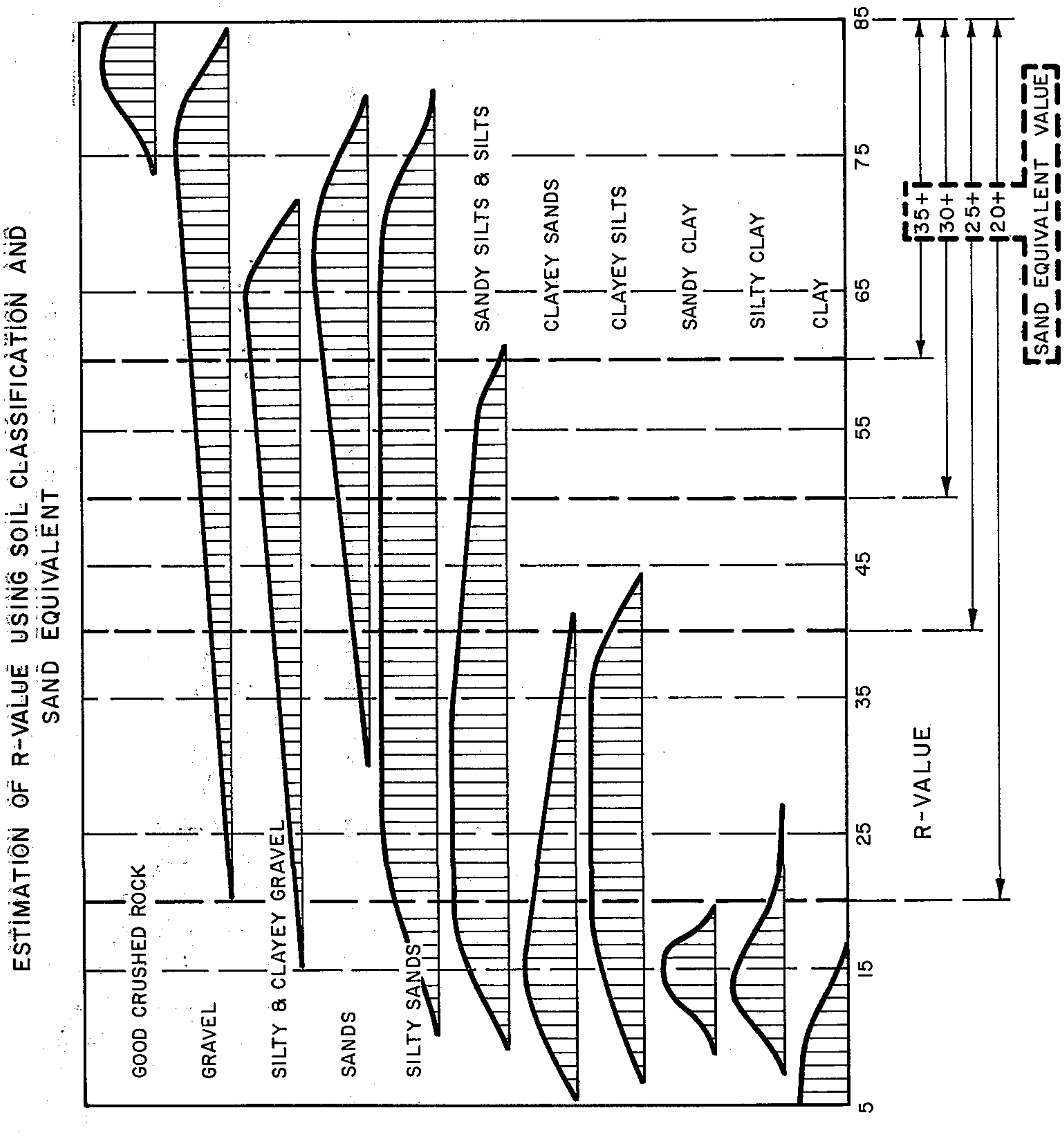


Figure 5



ESTIMATION OF R-VALUE USING SOIL CLASSIFICATION AND SAND EQUIVALENT
GOOD CRUSHED ROCK
GRAVEL
SILTY & CLAYEY GRAVEL
SANDS
SILTY SANDS
SANDY SILTS & SILTS
CLAYEY SANDS
CLAYEY SILTS
SANDY CLAY
SILTY CLAY
CLAY
5
15
25
35
45
55
65
75
85
R-VALUE
35+
30+
25+
20+
SAND EQUIVALENT VALUE

SLAB STRENGTH OF STRUCTURAL LAYERS

The term "strength", as used here, refers to the tensile strength or cohesion of the elements of a pavement structure. This ability to act as a slab serves to both reduce the pressure on the subgrade through beam action and to restrain the upward movement of soil around the loaded area. The slab action assumes minor importance in the lower levels of the structural section but increases in effectiveness as the upper surface is approached.

The effect of slab action is accounted for, in the thickness design formula, by the use of the gravel equivalent factor (Gf). The gravel equivalent factor represents the thickness of gravel necessary to produce a load distributing and soil restraining effect equal to that produced by the slab action of a one-foot thickness of the material being considered.

Gf values have been assigned to the various construction materials and are tabulated in Figure 8 and in Test Method No. Calif. 301. A graph illustrating the relationship between Gf for asphalt concrete and the Traffic Index is shown in Figure 6. This graph enables interpolation between the values shown in Figure 8 and allows the designer small advantages in economy if he chooses to design by the formula rather than by tables.

STRUCTURAL SECTION DESIGN PROCEDURE

Standard design procedure is shown in Test Method No. Calif. 301. This procedure uses the design formula and allows the designer to design each layer to the most economical thickness. Use of this formula requires all three variables: T.I., R-value, and Gf.

The design chart, which is the subject of Figure 7 is a repetition of a chart shown in the test method and offers a quicker approach to the design problem. Complete instructions for use of the chart are shown in Figure 8.

For those who do not wish to go to the trouble of using the iterative design procedure, structural design tables are provided in Figure 9. These tables present structural sections already worked out for various combinations of basement soil R-value, base and subbase R-value and Traffic Index. To use the tables, it is only necessary to know the basement soil R-value and the Traffic Index. The tables are for roads constructed with aggregate base having a minimum 78 R-value. One table is for 50 R-value

Figure 6

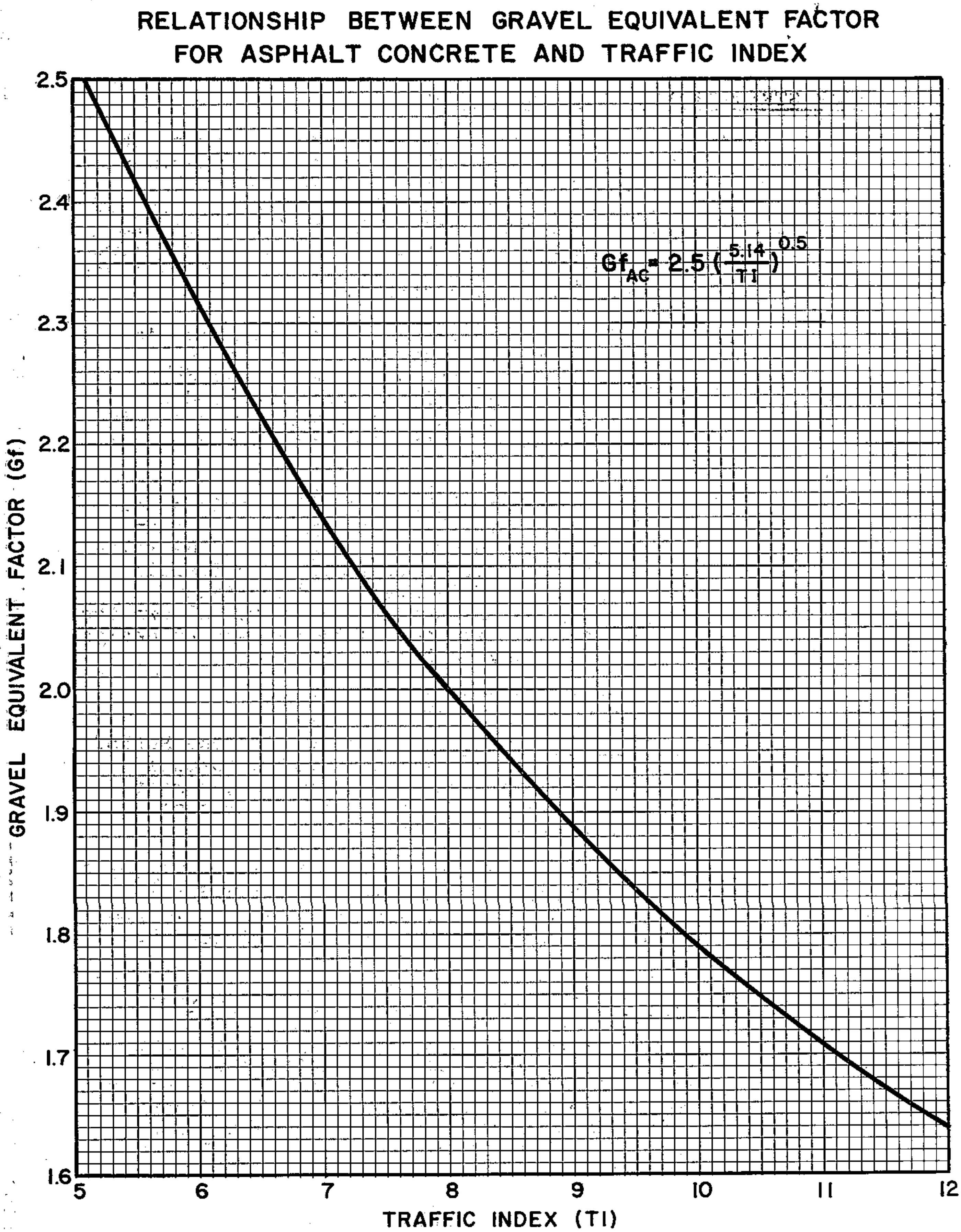
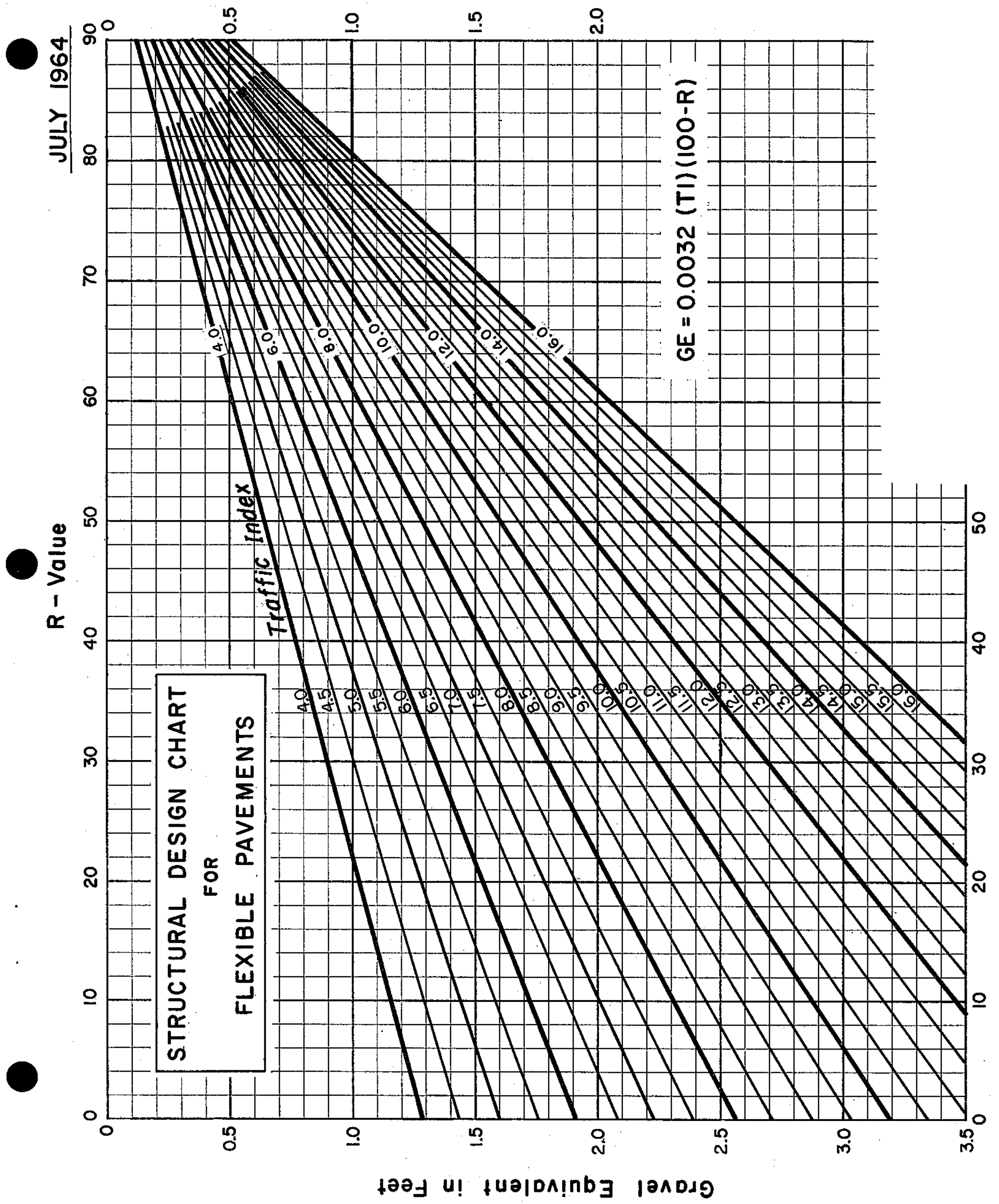

RELATIONSHIP BETWEEN GRAVEL EQUIVALENT FACTOR FOR ASPHALT CONCRETE AND TRAFFIC INDEX
$Gf_{AC} = 2.5\left(\frac{5.14}{TI}\right)^{0.5}$
GRAVEL EQUIVALENT FACTOR (Gf)
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
5
6
7
8
9
10
11
12
TRAFFIC INDEX (TI)

Figure 7



JULY 1964
STRUCTURAL DESIGN CHART
FOR
FLEXIBLE PAVEMENTS
GE = 0.0032 (TI) (100-R)
Traffic Index
R - Value
Gravel Equivalent in Feet
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
10
20
30
40
50
60
70
80
90
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10.5
11.0
11.5
12.0
12.5
13.0
13.5
14.0
14.5
15.0
15.5
16.0

Figure 8

INSTRUCTIONS FOR USE OF STRUCTURAL DESIGN CHART

1. Find total GE - Intersect TI line with basement soil R-value line and read GE.
2. Select type of base to be used.
3. Find GE of surfacing - Intersect TI line with base material R-value line (Use R-80 for Class "C" CTB) and read GE. For Class "A" and "B" CTB select the surfacing thickness from Table III below.
4. Find thickness of surfacing - Convert GE to actual thickness using T- GE/G or if thickness was found in Table III, solve for GE. Round off thickness to the nearest .05 foot or, preferably, to the next highest .95 foot and adjust the GE accordingly.
5. Find GE of surfacing + base - Intersect TI line with subbase material R-value line and read GE.
6. Find thickness of base - Subtract the adjusted GE found in Step 4 from the GE in Step 5 and convert the remainder to thickness using T = GE/G . Round off the thickness to the nearest .05 foot or, preferably, to the next highest .05 foot and adjust the GE accordingly.
7. Find thickness of subbase - Add the adjusted GE from Step 4 to the adjusted GE from Step 6 and subtract the result from the GE found in Step 1. Round off to the nearest .05 foot or, preferably, to the next highest .05 foot.

TABLE I GRAVEL EQUIVALENTS IN FEET

Actual Thickness in Feet	T.I.	ASPHALT CONCRETE 5 & Below	5.5 6.0	6.5 7.0	7.5 8.0	8.5 9.0	9.5 10.0	10.5 11.0	11.5 12.0	12.5 13.0	13.5 14.0	RMS BTB & LTB	CTB A	CTB B	CTB C	Agg. Base	Agg. Sub-Base
	Factor (G_f)	2.50	2.32	2.14	2.01	1.89	1.79	1.71	1.64	1.57	1.52	1.2	1.7	1.5	1.2	1.1	1.0
0.10		0.25	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.16	0.15	0.12					
0.15		0.38	0.35	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.18					
0.20		0.50	0.46	0.43	0.40	0.38	0.36	0.34	0.33	0.31	0.30	0.24					
0.25		0.63	0.58	0.54	0.50	0.47	0.45	0.43	0.41	0.39	0.38	0.30					
0.30		0.75	0.70	0.64	0.60	0.57	0.54	0.51	0.49	0.47	0.46	0.36					
0.35		0.88	0.81	0.75	0.70	0.66	0.63	0.60	0.57	0.55	0.53	0.42				0.39	0.35
0.40		1.00	0.93	0.86	0.80	0.76	0.72	0.68	0.66	0.63	0.61	0.48				0.44	0.40
0.45			1.04	0.96	0.90	0.85	0.81	0.77	0.74	0.71	0.68	0.54	0.77	0.68	0.54	0.50	0.45
0.50			1.16	1.07	1.01	0.95	0.90	0.86	0.82	0.79	0.76	0.60	0.85	0.75	0.60	0.55	0.50
0.55				1.18	1.11	1.04	0.98	0.94	0.90	0.86	0.84	0.66	0.94	0.83	0.66	0.61	0.55
0.60					1.21	1.13	1.07	1.03	0.98	0.94	0.91	0.72	1.02	0.90	0.72	0.66	0.60
0.65					1.31	1.23	1.16	1.11	1.07	1.02	0.99	0.78	1.11	0.98	0.78	0.72	0.65
0.70						1.32	1.25	1.20	1.15	1.10	1.06	0.84	1.19	1.05	0.84	0.77	0.70
0.75							1.34	1.28	1.23	1.18	1.14	0.90	1.28	1.13	0.90	0.83	0.75
0.80							1.43	1.37	1.31	1.26	1.22	0.96	1.36	1.20	0.96	0.88	0.80
0.85							1.52	1.45	1.39	1.33	1.29	1.02	1.45	1.28	1.02	0.94	0.85
0.90								1.54	1.48	1.41	1.37	1.08	1.53	1.35	1.08	0.99	0.90
0.95									1.56	1.49	1.44	1.14	1.62	1.43	1.14	1.05	0.95
1.00									1.64	1.57	1.52	1.20	1.70	1.50	1.20	1.10	1.00
1.05										1.65	1.60	1.26	1.78	1.58	1.26	1.16	1.05

SAFETY FACTORS

Where desired, the safety factors in Table II, below, may be applied to sections designed by the above method. For sections using aggregate bases and Class "C" CTB, add the GE increase from Table II to the GE found in Step 3. For sections with Class "A" and Class "B" CTB, add the GE increase to the GE found in Step 5. In each case, convert the new GE to thickness, round off the new thickness and adjust the GE accordingly. Since the addition of the safety factor should not change the total GE, the subbase thickness must be reduced to compensate for the increased thickness of the layer to which the safety factor was applied. For further explanation see Planning Manual - Design Sect. 7-604.

TABLE II STRUCTURAL SECTION SAFETY FACTORS

Base Type	Gravel Equivalent Increase in Feet	Layer Applied to
Class "A" CTB	0.24	CTB
Class "B" CTB	0.22	CTB
Class "C" CTB	0.18	AC
Aggregate Base	0.16	AC

TABLE III STRUCTURAL SECTION THICKNESS GUIDE

Type of Base Material	Pavement or Base Layer	Depth of Layer (Feet) TI 5.0 & below	TI 5.5 & 6.0	TI 6.5 & 7.0	TI 7.5 & 8.0	TI 8.5 & 9.0	TI 9.5 & 10.0	TI 10.5 & 11.0	TI 11.5 & 12.0	TI 12.5 & 13.0	TI 13.5 & 14.0
Class A CTB	Pave. Base				0.25 0.60	0.30 0.65	0.35 0.70	0.40 0.80	0.45 0.85	0.50 0.90	0.55 0.95
Class B CTB	Pave. Base			0.25 0.55	0.30 0.60	0.35 0.65	0.40 0.75	0.45 0.80	0.50 0.90	0.55 0.95	
Class C CTB	Pave. Base		0.25 0.45	0.30 0.55	0.35 0.65	0.40 0.70					
Class 1 AB 80R	Pave. Base	0.20 0.40	0.25 0.50	0.30 0.60	0.35 0.65	0.40 0.75	0.45 0.85	0.50 0.95	0.55 1.05	0.65 1.10	
Class 2 AB 78R	Pave. Base	0.20 0.40	0.25 0.50	0.30 0.60	0.35 0.65	0.40 0.75	0.50 0.80	0.55 0.90	0.60 1.00		

Notes: This table is intended for use as a guide. The thicknesses given are based on the higher TI in each column and the assumption is made that subbase with an R-value of 50 would be used. Extra thickness for a safety factor has already been added.

Figure 9

STRUCTURAL DESIGN CHART

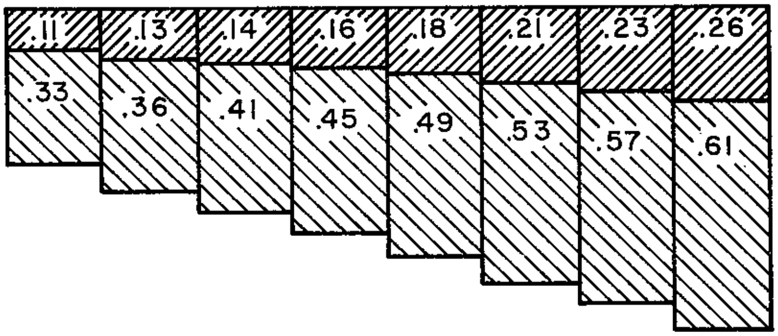
AC-AB (78R) -AS (50R)

TRAFFIC INDEX — 4 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.5

THICKNESS IN FEET

ASPHALT CONCRETE

AGGREGATE BASE



AGGREGATE SUBBASE

R-value	4	4.5	5.0	5.5	6.0	6.5	7.0	7.5
35	0.19	0.21	0.24	0.26	0.29	0.31	0.34	0.36
30	0.25	0.29	0.32	0.35	0.38	0.42	0.45	0.48
25	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60
20	0.38	0.43	0.48	0.53	0.58	0.62	0.67	0.72
15	0.45	0.50	0.56	0.62	0.67	0.73	0.78	0.84
10	0.51	0.58	0.64	0.70	0.77	0.83	0.90	0.96
5	0.58	0.65	0.72	0.79	0.86	0.94	1.00	1.08

R-VALUE OF BASEMENT SOIL

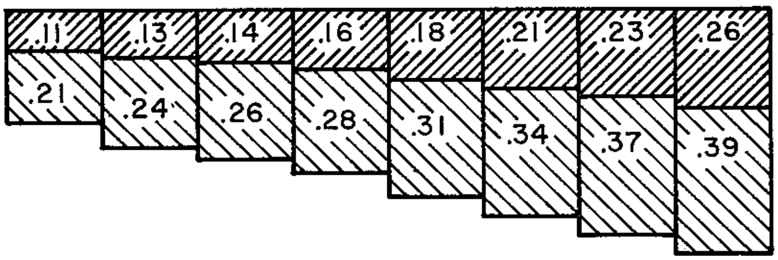
AC-AB (78R) -AS (60R)

TRAFFIC INDEX — 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.5

THICKNESS IN FEET

ASPHALT CONCRETE

AGGREGATE BASE



AGGREGATE SUBBASE

R-value	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
35	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60
30	0.38	0.43	0.48	0.53	0.58	0.63	0.67	0.72
25	0.45	0.50	0.56	0.62	0.67	0.73	0.78	0.84
20	0.51	0.57	0.64	0.71	0.77	0.83	0.89	0.96
15	0.58	0.64	0.72	0.80	0.86	0.94	1.00	1.08
10	0.64	0.72	0.80	0.88	0.96	1.04	1.12	1.20
5	0.71	0.79	0.88	0.97	1.06	1.15	1.23	1.32

R-VALUE OF BASEMENT SOIL

subbase and the other for subbase with a minimum R-value of 60. R-values for basement soils in the tables range from 5-35. If the designer so desires, these values may be rounded off, using judgment in so doing.

Having decided which quality of subbase is to be used, and knowing the design R-value of the basement soil, enter the selected table at the correct Traffic Index. Thicknesses of the various layers of the structural section can then be read opposite their respective headings.

The thicknesses shown satisfy the theoretical required thickness. However, common sense and knowledge of construction practice may, in the case of the thinner layers, dictate greater thicknesses of a particular material. In general, it is difficult to obtain good results with less than .12' - .13' (1-1/2") of asphalt concrete. It is also very difficult to properly place and compact layers of aggregate base or subbase when these layers measure less than .33' (4"). Since it is difficult to prevent some intermingling and interpenetration of the various layers, it might be wise to establish .4' (5") as a minimum thickness for bases and subbases.

If a design calls for a thin aggregate base layer as well as a thin aggregate subbase layer, it might be well to combine the two and place a layer of base equal to the total thickness. This would save placing costs and give a better design. This discussion applies, of course, to any method of design.

The tables in Figure 9 do not include safety factors other than those inherent in the design formula.

For the design of sections using bases other than aggregate base, it is necessary to go to the standard method or use Figure 7.

STRUCTURAL SECTION DESIGN EXAMPLE

To illustrate a typical design, the following example is presented. Although the example uses the design formula, it is so structured that the engineer may also follow through with the more approximate methods.

Problem: Design a structural section for a county farm-to-market road based on the following traffic counts and laboratory test data, using a ten year design period. Average daily traffic (ADT) is around 530 with about 10% truck traffic.

Two-way Truck Traffic Counts

Truck Category	Present ADTT
2-axle (6 tire)	62
3-axle	10
4-axle	4
5-axle	12
6-axle	0

It is estimated that truck traffic 10 years after construction will be 2.0 times the present truck traffic except for 5-axle trucks which are estimated to increase 1.5 times present traffic in the same period. Estimates were arrived at after consultation with planners and consideration of future land use.

Laboratory Soil Test Data

Test results from:

	Location 1	Location 2	Location 3
Sand Equivalent	5	7	9
R-value	10	12	15
Grading Analysis:			
% Passing No. 8	100	100	100
% Passing No. 200	73	60	39
% Passing 5 Micron	32	26	15

Visual inspection along the route indicates that three main soils are present. The location runs through an old flood plain and the soils are intermingled and hard to delineate.

Solution:

Step 1 - Determine traffic expansion factors

5-axle trucks $\frac{1 + 1.5}{2} = 1.25$

Other trucks $\frac{1 + 2.0}{2} = 1.50$

Note that this is a "mid-period" factor which, when multiplied by average annual EWL* and number of years in the design period, will yield total EWL. Determination of this factor entails considerable engineering judgment and consideration of overall area development.

*EWL = Equivalent 5,000 pound wheel loads

Step 2 - Determine Equivalent 5,000 pound Wheel Load Repetitions (EWL). The truck counts indicate a normal mixture of farm-to-market traffic so that the City-County EWL constants may be used as is.

Truck Category	Present ADT	Expansion Factor	Expanded ADT	EWL Constants	Annual EWL
2-axle (6 tire)	62	1.5	93	200	18,600
3-axle	10	1.5	15	690	10,350
4-axle	4	1.5	6	1070	6,420
5-axle	12	1.25	15	1700	25,500
6-axle	0	-	0	1050	0
				Total Annual EWL =	60,870

Total 10-year EWL = 10 x 60,870 = 608,700

Step 3 - Convert Total EWL to Traffic Index

$$TI = 6.7 \left(\frac{\text{Total EWL}}{10^6}\right)^{0.119}$$

$$TI = 6.7 \, (0.61)^{0.119}$$

$$TI = 6.7 \times .943 = 6.32$$

Use TI = 6.5 rounding off to nearest 0.5

Equation 2, Appendix A (or from Table A-1 or Figure A-2)

Step 4 - Interpretation of Laboratory Test Data.

The design method is based on the R-value test data. The sand equivalent values and grading analyses on the same soil samples are used for supplemental information to aid in classifying the material encountered.

An important point to remember is that the samples taken must be representative of material which will lie immediately under the planned structural section.

An R-value of 10 should be used in designing a structural section for this project since it represents the lowest quality material encountered and the materials are so intermingled that it is not feasible to change the design R-value to take advantage of the better material.

Step 5 - With the data obtained thus far, we may now design the structural section using a TI of 6.5 and an R-value of 10 for basement soils.

For illustration purposes, let us assume that it is desired to use Type "B" Asphalt Concrete, Class 2 Aggregate Base, and Class 2 Aggregate Subbase as the materials in the structural section.

Step 5a - Find the equivalent thickness of gravel required (gravel equivalent, or simply GE) for the Asphalt Concrete Pavement which will be placed over Class 2 Aggregate Base (78 Min. R-value material).

$GE = 0.0032\ (TI)\ (100-R)$ From Figure 7
$GE = 0.0032\ (6.5)\ (100-78)$
$GE = 0.46'$ required

Next, for a Traffic Index of 6.5, we obtain a gravel factor of 2.22 for Asphalt Concrete from Figure 6.

$$\text{Thickness of AC required} = \frac{0.46'}{2.22} = 0.21'$$

Rounding to the nearest 0.05', use 0.20' AC

Step 5b - Find the thickness of Aggregate Base required

Class 2 Aggregate Subbase consists of 50 Min. R-value material

GE over 50 R-value material = .0032 x 6.5 x 50	= 1.04'
Deduct GE furnished by AC = 2.22 x 0.20'	= -0.44'
GE required for Aggregate Base	= 0.60'

Next we obtain a gravel factor of 1.10 for AB from Figure 8.

$$\text{Thickness of AB required} = \frac{0.60}{1.10} = 0.55'$$

Use 0.55' Cl. 2 AB

Step 5c Find the thickness of Aggregate Subbase required over basement soils with an R-value of 10 Min.

GE required over 10 R-value matl. = .0032 x 6.5 x 90		= 1.87'
GE furnished by 0.20' AC(from above) =	-0.44'	
GE furnished by 0.55' AB(1.10x0.55) =	-0.60'	-1.04'
GE of Cl. 2 AS required		0.83'

Gravel factor for Agg. Subbase is 1.0 (from Figure 8)
Hence the thickness of Cl. 2 AS required = 0.83'
Rounding to the nearest 0.05', Use 0.85' Cl. 2 AS

Step 5d - Check to see that adequate overall cover requirements are satisfied.

Total GE required = 1.87' (from page 17)
Total GE furnished with
0.20' AC x 2.22 = 0.44' gravel
0.55' AB x 1.10 = 0.60' "
0.85' AS x 1.00 = 0.85' "
1.89' "

1.87' required; 1.89' furnished, therefore the structural section furnished is adequate, for each layer of material and for total cover required.

Comparing the above design with an approximate method, the engineer may enter the chart in Figure 1 by making a reasonable assumption about overall traffic 10 years in the future. Suppose it is assumed that the ADT will increase 50% and percentage of trucks will remain the same. If the ADT goes up 50%, the average will be 1.25 times the present ADT. Entering Figure 1 with 1.25 x 600 or ADT = 750 with 15% trucks, the TI is found to equal 6.8.

Entering the triangular chart in Figure 4 with the clay, silt, and sand percentages for the three basement soils, it is found that the soils are: silty clay, clayey silt and sand, and silty sand, respectively. Looking at the chart in Figure 5 and considering both the soil classification and the sand equivalent, it is obvious the silty clay will be the most critical material. The appearance of the R-value frequency curve for silty clay in Figure 5 and the sand equivalent value of 5 lead one to choose an R-value in the lower tail of the curve, probably between 8 and 10.

Then, going to the structural design chart (Figure 9) and entering the top chart (AS = 50 R-value) with a 7.0 TI and a R-value between 5 and 10, the following structural section is found.

AC .23'
AB .57'
AS .95'

THE SAFETY FACTOR

The basic thickness design formula contains sufficient built-in safety factor for low-volume roads and streets. Facilities with a T.I. of 8 and over might benefit from use of the safety factors shown in Figure 8. The factors are particularly needed where ADT and T.I. are high, but truck percentages are low. In this type of situation, traffic density all but precludes normal maintenance operations. It is best in these cases to construct a section with a long, maintenance-free life. Additional information on the application of the safety factor is shown in the California Division of Highways Planning Manual (1).

ECONOMIC COMPARISON OF SECTIONS

Many situations allow comparison of several structural sections, each of which meets design criteria. An economic analysis may aid in the selection of the best section. It is necessary to determine the construction cost of each alternative.

In addition to cost, final selection will also depend upon local practices, construction experience, suitability of the materials for their intended use, expected service life, climatic conditions, future maintenance, and other considerations.

STAGE CONSTRUCTION

Stage construction of a road is sometimes proposed as a money-saving expedient or as a device to lengthen the improvement for a particular highway. When stage construction is properly planned and executed, it usually performs as intended.

It is essential to remember that the road be designed for the same criteria which would govern the design of a fully completed facility for that location. The individual layer thicknesses of the design should not be compromised. Full thicknesses of subbase and base should be placed since it is impracticable to add to them later on.

The surfacing is usually the only item in the structural section affected by stage construction. In some cases, the surfacing is deferred for several years and only a road-mixing of the upper portion of the base or placement of an armor coat is provided initially for traffic. Other projects are designed with some portion of the surfacing thickness placed at the time of construction and the rest later on.

In any case, a definite time schedule should be fixed for the completion of stage construction. The project should be carefully watched during the interim period between construction and completion and upon indication of trouble, should be completed to the full design thickness.

CHANGES TO R-VALUE TEST

It is sometimes suggested that it would be advantageous to determine the R-value in semi-arid parts of California at 400 psi exudation pressure rather than 300 psi as currently specified. This is not always a safe practice. The Division of Highways investigated the relationship between moisture contents under pavements and exudation pressure (4) and concluded that 300 psi more nearly represented field conditions.

If the engineer designing the pavement structure is thoroughly knowledgeable with respect to the pitfalls in structural design and if he has engineering data to back up his judgment, he might be justified in using an R-value at other than 300 psi exudation pressure. This would apply primarily to areas with low rainfall where the soils have good drainage characteristics.

The structural section, however, should be designed for the worst moisture condition that can be expected, not the average condition. Moisture tends to concentrate under pavements, even in drier climates. This condition can be aggravated by irrigation water, heavy rains and other sources of water.

OVERLAY DESIGN USING PAVEMENT DEFLECTION

General

With a steadily increasing amount of reconstruction of existing roadways, the need for a method to determine the minimum corrective treatment required to restore an existing roadbed to a state in which it may serve present-day traffic and provide maintenance-free service for an extended period of time has become increasingly important.

The problem encountered in the design of reconstruction is, of course, entirely different from that which occurs with all-new construction. In the latter case, samples of basement or embankment soils are tested statically under moisture and density conditions which are estimated to be the worst that will occur during the lifetime of the pavement. From the results of these tests, subgrade bearing capacity is determined with which the necessary thickness of base or subbase can be calculated to provide the required cover in accordance with the appropriate design formula.

The design of reconstruction for an existing roadway presents quite another problem, however, since the most economic reconstruction requires that full benefit be derived from the materials already existing in the structural section. In this case, a laboratory strength value cannot be considered quite valid, since the conditions of moisture and density assumed during preliminary design may not have occurred. Also, it is well established that many years of successively heavier traffic loadings tend to gradually increase in-place soil strength. Another factor which is difficult to evaluate is the residual strength of an asphalt concrete surfacing or cement-treated base. Here the hardening or curing induced by age may lend considerable slab strength to the system even though there is continuous visible distress.

The real significance of pavement deflection data, therefore, is that it gives the highway engineer an indication of the total in-place structural strength of an existing roadway and, thus, provides an extremely valuable tool for the determination of the minimum degree of required reconstruction.

Basic Data

Basically, the method consists of measuring the total pavement deflection resulting from the application of a known wheel load (15,000 pounds) along the road under investigation. The deflection readings are then compared to previously determined allowable limits for a similar structural section and the structural capability of the existing flexible pavement is evaluated. Then an appropriate corrective treatment is determined if any is required.

Three pavement deflection measuring devices are briefly described below:

1. Benkelman Beam

   This instrument, developed by Mr. A. C. Benkelman of the Bureau of Public Roads, operates on a simple lever arm principal. An 8-feet-long probe is inserted between the dual tires of the test vehicle. As the pavement is depressed, the beam pivots around a point of rotation on the reference beam which rests on the pavement well behind the area of influence, so that the back four-feet extension of the beam depresses an Ames dial which records maximum deflection to within 0.001". While this device is limited to measurements of total deflection only for test vehicles operating at creep speed, it has the very important advantages of simplicity, versatility, and speed. Between 200 and 300 individual deflection measurements are possible in a day with this device.

2. <u>Traveling Deflectometer</u>

This instrument, developed by the Materials and Research Department of the State Division of Highways, is a semi-automatic deflection measuring device based upon the Benkelman beam principle.

The traveling deflectometer combines a truck-trailer unit which carries the test load on the rear wheels and probes for measuring pavement deflection under both wheels simultaneously. It is an electro-mechanical instrument capable of measuring pavement deflections at 12-1/2 foot intervals uniformly and continuously as the vehicle moves steadily along the road at one-half mile per hour. The deflections are recorded to the nearest 0.001" by means of a probe arm resting on the pavement and are permanently recorded on chart paper. As many as four simultaneous measurements (two between the wheels and two outside the outer duals) at 12-1/2 foot intervals are possible. The most obvious advantage of the deflectometer, therefore, is the relatively large volume of data which may be accumulated in a relatively short period of time. Between 1500 and 2000 individual deflection measurements can be made during an average working day as compared to the 300 which is the current maximum obtainable with the Benkelman beam and truck arrangement.

3. <u>Lane-Wells Dynaflect</u>

This unit, developed by the Lane-Wells Company of Houston, Texas, is an electro-mechanical system for measuring the dynamic deflection of a roadway surface by an oscillatory load.

The dynaflect consists of a self-contained mobile trailer which can be towed behind a passenger vehicle and operated by the driver from inside the tow vehicle. The trailer, when in the test position, exerts a 1,000 pound peak to peak oscillatory load onto the pavement surface through two steel test wheels. The resultant amplitudes or deflections are recorded to within 0.00001" by a series of five geophone sensors positioned at one foot intervals out from the center of loading along the tongue of the trailer.

Benkelman beam deflection measurements can be predicted for overlay design purposes utilizing a pre-established correlation between Dynaflect deflection and Benkelman beam deflection. The Materials and Research Department of the California Division of Highways have an established correlation curve for these two deflection devices.

The Dynaflect is capable of obtaining deflection measurements on unsurfaced roadways because of its light, well distributed test load. Although it is not capable of producing the volume of data which is possible with the traveling deflectometer, it can be much more economical for operational deflection studies of a limited nature in outlying areas due to its high mobility and ease of operation.

Design Procedure

It should be borne in mind that the deflection method for the design of reconstruction is assumed to be valid when roadway distress is attributable to excessive compression and rebound of the structural section. Evidence of the instability of the structural section, as manifested by wheel track depression or rutting or indication of significant permanent deformation on the deflection traces reveals a problem beyond the scope of the deflection method. In these cases, design of corrective treatment should be based upon R-value procedures.

Therefore, the first step of this design procedure is to visually inspect the existing road, noting those areas that would obviously require a complete "dig-out" type of repair. By-passing these areas of severe distress, deflection readings are taken over the remainder of the road. The actual pavement deflections are measured and recorded under both the outer wheel track (O.W.T.) and inner wheel track (I.W.T.) of the loaded test truck.

If these deflection readings are not relatively uniform for a given stretch of road, then more than one type of corrective treatment may be required. In those areas where deflection is relatively uniform, an evaluated deflection level (80 percentile) is established by recombining all outer wheel track readings from the test section.

The 80 percentile value is that deflection at which 80 percent of the recorded values are lower and 20 percent of all the readings are higher. This 80 percentile value reflects the deflection characteristics of the section as a whole rather than isolating possible causes of distress or placing undue emphasis on an isolated condition.

The 80 percentile deflection value is then compared to the allowable deflection for a similar road subject to the same traffic loading (see Figure 10). If the deflection is greater than the allowable, the percent of required reduction of deflection is computed. Entering the graph on Figure 11 with the required percent reduction, the required increase in gravel equivalent for the road can be readily ascertained.

Design Example

In order to illustrate the method of analysis and procedure for recommendation of corrective treatment based upon deflection data, we shall examine what might be considered a typical case history of a particular roadway.

Assumed Data:

T.I. = 6.5

Existing structural section: 2" AC surfacing over
4" of aggregate base over
4" of aggregate subbase.

Test Sec.	Deflection (O.W.T.) 80%	Number of Readings	Appearance
1	.064	28	Intermittent to continuous "alligator" cracking

Based upon a T.I. of 6.5 and the assumption that a 3 inch AC surfacing recap will be utilized, it is determined from Figure 10 that a deflection level of 0.030" can be tolerated. It is, therefore necessary to effect a reduction in the deflection level of 0.064" minus 0.030", or 0.034". This requires a $\frac{0.034''}{0.064}$ = 53% reduction in deflection. From Figure 11 we note that an increase of 10.5" in gravel equivalence is required to reduce the deflection level by 53%. For a 3" AC surfacing the gravel equivalence is 3.0 x 1.9" = 5.7". It will, therefore, be necessary to provide 10.5" minus 5.7" = 4.8" of additional gravel. A possible reconstruction would, therefore, be the placement of a 3" AC surfacing over 5.0" of aggregate base directly over the existing roadway.

Another practical approach to the same problem which would cost less takes into consideration the type of distress on the roadway. Here we note intermittent to continuous "alligator" cracking in both wheel tracks. Because "alligator" cracks are usually small (2" to 5" in diameter) we can reasonably assume that the existing pavement will act independently of the new surfacing in much the same manner as an aggregate base. Therefore, consideration should be given to the possibility of the placement of a thin AC blanket which would permit a higher tolerable deflection level. This approach could be considered "living" with a high deflection condition rather than eliminating it by a major reconstruction. For a 2" AC surfacing Figure 10 indicates a tolerable deflection of 0.040". It would, therefore, be necessary to reduce the design deflection level of 0.064"

Figure 10

VARIATION IN TOLERABLE DEFLECTION BASED ON A.C. FATIGUE TESTS

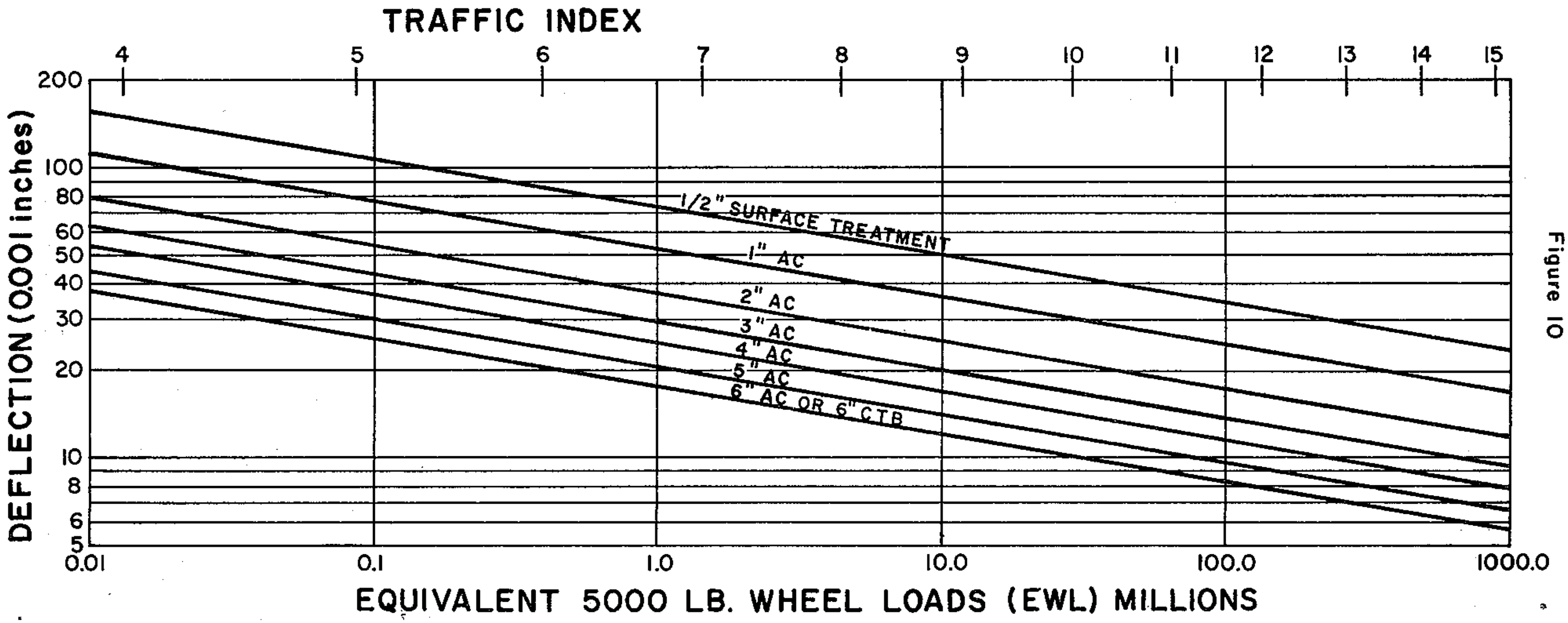
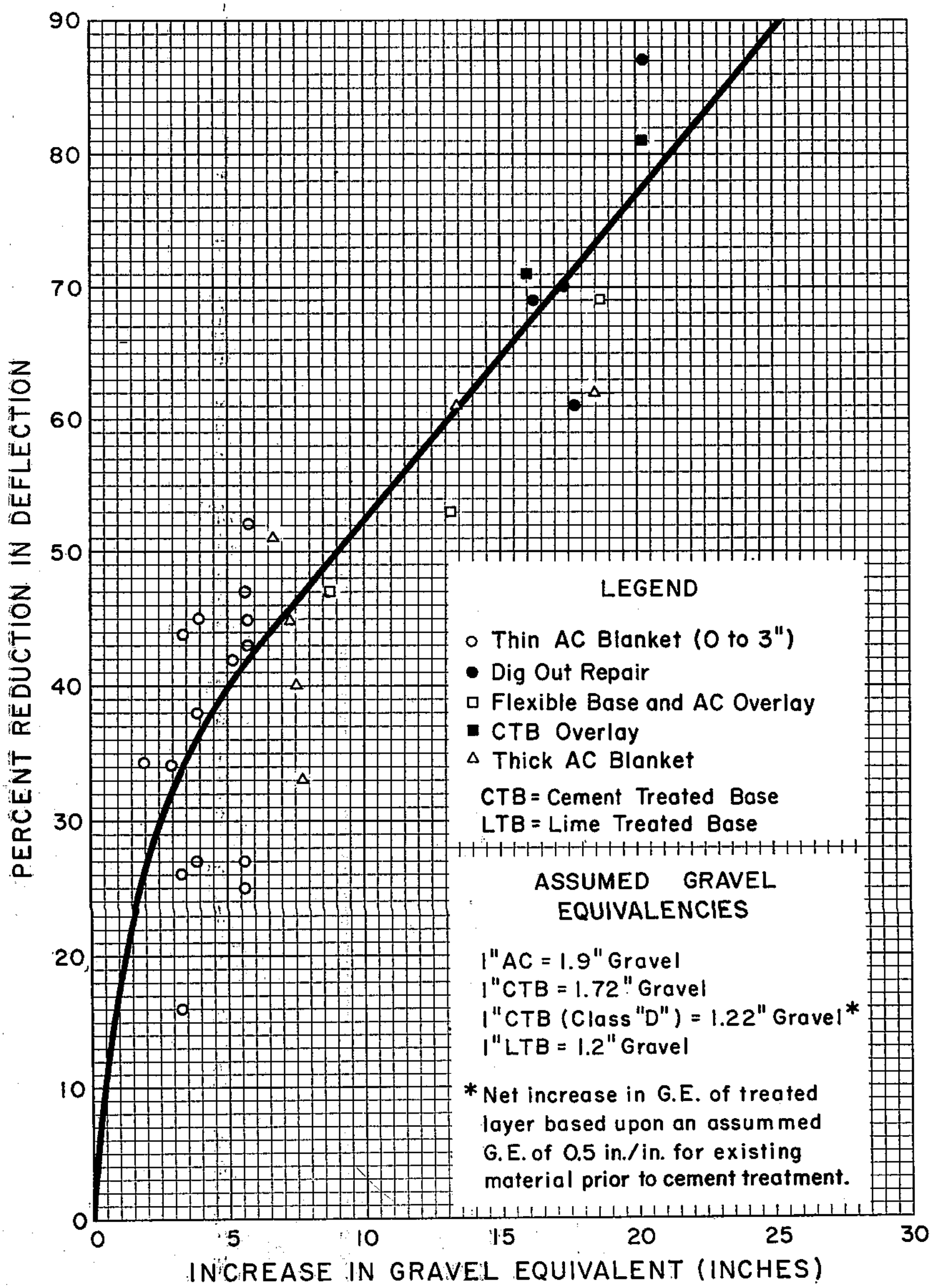


Figure 11

REDUCTION IN DEFLECTION RESULTING FROM PAVEMENT RECONSTRUCTION



to 0.040" which requires a 38% reduction in deflection. From Figure 11, a 2" AC blanket (3.8" gravel equivalence) provides a 37% reduction in deflection. This is considered close enough to recommend a 2" AC surfacing for the repair of this facility.

In either case, isolated areas of high transient deflection or advanced distress should be subject to substantial "dig-out" type repair prior to the application of the corrective treatments described above.

Additional Considerations

The problem of recommending suitable reconstruction is not limited to a study of deflection measurements; several other factors must also be considered in order to arrive at a satisfactory design. These are:

1. Existing vertical controls (curbs and gutters)
2. Anticipated use of the roadway
3. Extent and nature of cracking
4. Anticipated traffic volume

The existence of curbs and gutters or the presence of an excellent passing lane next to a distressed travel lane often makes the utilization of a travel lane "dig-out" feasible. Where no such vertical control exists and a major reconstruction is warranted, a flexible base or cement-treated base (CTB) with an asphalt concrete (AC) blanket is usually recommended so that the residual strength of the old pavement can be incorporated into the new construction.

The anticipated future use of a roadway frequently determines whether we shall "live" with a deflection condition through utilization of a thin blanket or eliminate the problem with major reconstruction.

The extent and nature of cracking is frequently very important in determining whether a blanket will act independently of the old surfacing or become an integral part of the existing surfacing, thereby increasing surface rigidity with a corresponding decrease in the level of tolerable deflection.

The presence of large block or ladder-type cracks indicates that the existing surfacing has a good deal of residual slab strength and could thus be expected to act in conjunction with a new blanket. Thus, the AC surfacing would consist of the original and the repair blanket, acting as a unit. Because of this, the tolerable deflection level would be much lower than that for a new blanket applied to a continuously cracked AC surfacing in which surface distress is in the form of relatively small blocks as is sometimes the case with badly "alligator" cracked roads. Here, because the new blanket can be considered independent of the old, the tolerable deflection level can be assumed to be determined by the thickness of the new blanket only.

Finally, since allowable deflection limits are a function of traffic volume (see Figure 10) any anticipated sizeable increase in T.I. would affect the recommended reconstruction.

CBR DESIGN METHOD

General

Some agencies do not have access to R-value determination equipment, but do have the facilities or ready access to such equipment necessary to determine CBR (California Bearing Ratio) values. The nomograph (Figure B-1) will provide a means of determining a structural section by converting the known CBR to an equivalent R-value. The nomograph must be used with extreme care since there is no direct correlation between R-value and CBR. The nomograph is more accurate when considering fine-grained soils than it is when working with gravelly soils.

Basic Data

The CBR values should be determined in conformance with procedures set forth in the State of California Standard Specifications dated January, 1949(5), or in conformance with test method ASTM D 1883-67(6). The State of California method, as outlined in Appendix B, is preferred.

Comments

The bearing ratio test is used to determine the bearing ratio (relative bearing value compared to that of crushed rock) at optimum moisture and maximum density, after soaking, of material proposed for use on the roadway.

The expansion test is used to determine the expansion of a compacted specimen of material proposed for use, after soaking for a period of four (4) days. The test is made on a compacted specimen used in the bearing ratio test referred to above.

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APPENDIX A

METHOD FOR CALCULATING EQUIVALENT WHEEL LOADS, TRUCK CONSTANTS, AND TRAFFIC INDICES

SCOPE

This method describes the procedure for transforming traffic count data into descriptive numbers which are used in calculating the structural thickness of pavement.

DEFINITIONS

Traffic Index (TI) - a number representing the weight and volume of truck traffic on a given section of highway.

Equivalent Wheel Load (EWL) - the number of repetitions of a 5,000 pound wheel load which would have the same damaging effect as the truck axle or axles being considered.

Average Daily Truck Traffic (ADTT) - the number of trucks passing a given point on a highway, in both directions, in any 24-hour period.

Truck Constant - (EWL Constant) - a number expressing the total EWL generated by the passage of an average truck of a particular type, once a day, in one direction, for a period of one year.

PROCEDURE FOR CALCULATING TRAFFIC INDEX

For structural thickness design purposes, the average daily truck traffic must be converted into a traffic index. Initially, we must convert all axle loads[1] to an equivalent number of 5,000 pound wheel loads by using the equation:

$$\text{EWL/Repetition} = \left(\frac{W}{5}\right)^{4.2} \qquad (1)$$

Where: EWL = equivalent 5,000 pound wheel loads for one repetition of a particular average wheel load

W = Average wheel load in kips

The graphical solution to this equation is presented in Figure A-1 along with an example showing that one 5,000 pound wheel load would have a constant EWL of 1.0.

[1]Treat a tandem unit as two single axles each carrying one-half the tandem unit load.

To determine total EWL, multiply the repetitions of the axle load by the EWL per repetition.

To convert the total EWL to a traffic index, use the following equation:

$$TI = 6.7 \left(\frac{EWL}{10^6}\right)^{0.119} \qquad (2)$$

This equation is solved graphically in Figure A-2 and is presented in tabular form below:

TABLE A-1

Conversion of EWL to Traffic Index

EWL	TI*	EWL	TI*
104		15,000,000	
	2.5		9.5
562		23,400,000	
	3.0		10.0
2,290		35,600,000	
	3.5		10.5
7,620		53,100,000	
	4.0		11.0
21,800		77,900,000	
	4.5		11.5
55,600		112,000,000	
	5.0		12.0
129,000		159,000,000	
	5.5		12.5
277,000		223,000,000	
	6.0		13.0
558,000		308,000,000	
	6.5		13.5
1,060,000		420,000,000	
	7.0		14.0
1,940,000		568,000,000	
	7.5		14.5
3,400,000		759,000,000	
	8.0		15.0
5,750,000		1,000,000,000	
	8.5		15.5
9,420,000		1,320,000,000	
	9.0		
15,000,000			

*Traffic Index = $6.7 \left(\frac{EWL}{10^6}\right)^{0.119}$

In order to convert mixed truck traffic to equivalent 5,000 pound wheel loads, it is necessary to have a sampling of the truck traffic, using the highway, by axle weights and by number of axles. This information, for a state-wide count, is made available each year by the Traffic Department in its W-4 tables. Convert the number of axles in a given weight category to the equivalent 5,000 pound wheel loads by using equation (1).

In practice, the calculations for TI are made by using <u>truck constants</u> for trucks in the following categories: 2, 3,4, 5, and 6 axle trucks. These constants are derived as follows:

1) Obtain loadometer data - (axle weight for all trucks listed by truck category) - and a classified traffic count.

2) Separate the axle weights in each truck category into axle weight intervals as shown in Table A-2.

3) Calculate the average wheel load for each weight interval and convert to average EWL/repetition by the relationship

$$EWL = \left(\frac{W}{5}\right)^{4.2}$$

(Table A-3). This average EWL/repetition is then multiplied by the number of axles in each weight interval. This yields a total EWL for each truck category in each weight interval for the period encompassed by the loadometer survey.

4) The EWL's in each truck category are then summed up.

5) Knowing, then, the total EWL's and the total number of axles for each truck category, the average EWL/axle can be calculated for each category.

6) The truck constant for each truck category is then obtained by multiplying the average EWL/axle by 365 days and by the number of axles on one truck in that category. The result is divided by two in order to reduce to a uni-directional constant.

Constants have been calculated by the Division of Highways from the State-wide traffic count and are listed in Table A-5. The State-wide constants should only be used in cases where more accurate truck traffic data is not available.

7) To calculate annual EWL, the truck constants for each truck category are multiplied by the average daily truck traffic and the anticipated increase factor. The resulting totals for each truck category are summed up to obtain the total average annual EWL's in one direction.

8) For use in the thickness design equation, the total annual EWL's are multiplied by the number of years in the design period and are then converted to Traffic Index (TI) by the relationship shown in Equation (2).

To clarify the preceding explanation, the following hypothetical example is shown:

Given: Loadometer traffic count data as indicated in Table A-2. Average daily traffic as given in Table A-4.

Required: To determine the truck constants for the truck traffic and establish a traffic index for the section of highway involved for a twenty year design life.

SOLUTION:

TABLE A-2

LOADOMETER TRAFFIC COUNT DATA
(BOTH DIRECTIONS)

Axle Weight Intervals (Kips)	No. Axles Weighed				
Single Axles	2-axle (6 tire) Trucks	3-axle Trucks	4-axle Trucks	5-axle Trucks	6-axle Trucks
Under 3.0	11,561	22	43	52	9
3.0 - 6.9	1,092	1,186	187	2,169	57
7.0 - 7.9	438	384	27	710	25
8.0 - 11.9	952	810	59	1,300	90
12.0 - 15.9	433	464	19	888	24
16.0 - 17.9	41	108	10	910	7
18.0 - 18.0	2	8		75	
Tandem Axles[1]					
Under 6.0		4	18	22	6
6.0 - 11.9		282	446	1,794	100
12.0 - 17.9		262	236	882	52
18.0 - 23.9		178	162	536	74
24.0 - 29.9		130	154	1,672	98
30.0 - 31.9		82	66	1,058	6
32.0 - 32.0		6	4	62	4
Total Number Axles	14,519	3,926	1,431	12,130	552

[1]Treat a tandem unit as two single axles, each carrying one-half the tandem unit load. For this reason the tabulated figures are actually twice the number of tandem axles counted.

TABLE A-3

CALCULATIONS FOR TRUCK CONSTANTS

Axle Weight Intervals (Kips)	EWL per Repetition[1]	2-axle (6 tire) Trucks	3-axle Trucks	4-axle Trucks	5-axle Trucks	6-axle Trucks
Single axles Under 3.0	0.006	69[2]	0	0	0	0
3.0 - 6.9	0.055	60	65	10	119	3
7.0 - 7.9	0.299	131	115	8	212	7
8.0 - 11.9	1.00	952	810	59	1,300	90
12.0 - 15.9	4.11	1,780	1,907	78	3,650	99
16.0 - 17.9	9.28	380	1,002	93	8,445	65
18.0 - 18.0	11.7	23	94	0	878	0
Tandem Axles Under 6.0	0.006[3]		0	0	0	0
6.0 - 11.9	0.035		10	16	63	4
12.0 - 17.9	0.299		78	71	264	16
18.0 - 23.9	1.23		219	199	659	91
24.0 - 29.9	3.53		459	544	5,902	346
30.0 - 31.9	6.30		517	416	6,665	38
32.0 - 32.0	7.20		43	29	446	29
Total EWL's		3,395	5,319	1,523	28,603	788
Total No. Axles[4]		14,519	3,926	1,431	12,130	552
Average EWL/Axle[5]		0.234	1.355	1.064	2.358	1.428
Truck Constants[6]		85	740	775	2,150	1,565

[1] Calculated from equation (1) or obtained from Fig. A-1. Use average wheel load. (Ave. wheel load = Ave. axle load divided by 2)

[2] EWL/Axle multiplied by number of axles. (No. of axles from Table A-2)

[3] These constants calculated for one-half of the average tandem axle load.

[4] From Table A-2.

[5] Total EWL's divided by Total No. of Axles.

[6] EWL/Axle x 365 days x No. Axles on each truck divided by 2 directions.

TABLE A-4

CALCULATION OF ANNUAL EWL

Truck Category	Average Daily[1] Truck Traffic	x	Truck[2] Constants	x	Anticipated[3] Increase Factor	=	EWL By Truck Category
2-axle (6 tire)	337		85		2.30	=	65,900
3-axle	182		740		1.90	=	255,900
4-axle	93		775		1.75	=	126,100
5-axle	276		2,150		2.10	=	1,246,100
6-axle	40		1,565		1.50	=	93,900
			Total Average Annual EWL's			=	1,787,900

Computing the total design EWL for 20 years:

$$EWL_{20yr.} = 1,787,900 \times 20 = 35,800,000^{4}$$

Traffic Index (TI) is calculated from the EWL by the use of equation (2), Table A-1, or from Fig. A-2

$$TI = 6.7 \left(\frac{EWL}{10^6}\right)^{0.119}$$

$$= 6.7 \left(\frac{35,800,000}{10^6}\right)^{0.119}$$

$$= 6.7 \; (35.8)^{0.119}$$

$$= 6.7 \quad 1.53$$

$$= 10.25 \text{ use a TI of } 10.5$$

This value of 10.5 for Traffic Index can now be used in the pavement structural thickness design equation, as explained in Test Method No. Calif. 301.

---

[1]Two directional count.

[2]These constants are for this example only and are not to be used in any actual calculations. Use the constants given near the end of this Test Method if applicable.

[3]This factor converts average daily truck traffic from the present count to the anticipated average count for the mid-year of the design period.

[4]Three significant figures are adequate for the accuracy of the method and data.

SPECIAL CASES Where a one-directional count is given, such as is the case for a one-way street, the truck constants should be doubled. The truck constants are based on a two-directional count. Notes: For cases where reliable traffic data is not available or traffic conditions can be considered average for a state-wide count, the EWL Truck Constants given in Table A-5 can be used in place of computing Truck Constants.

TABLE A-5

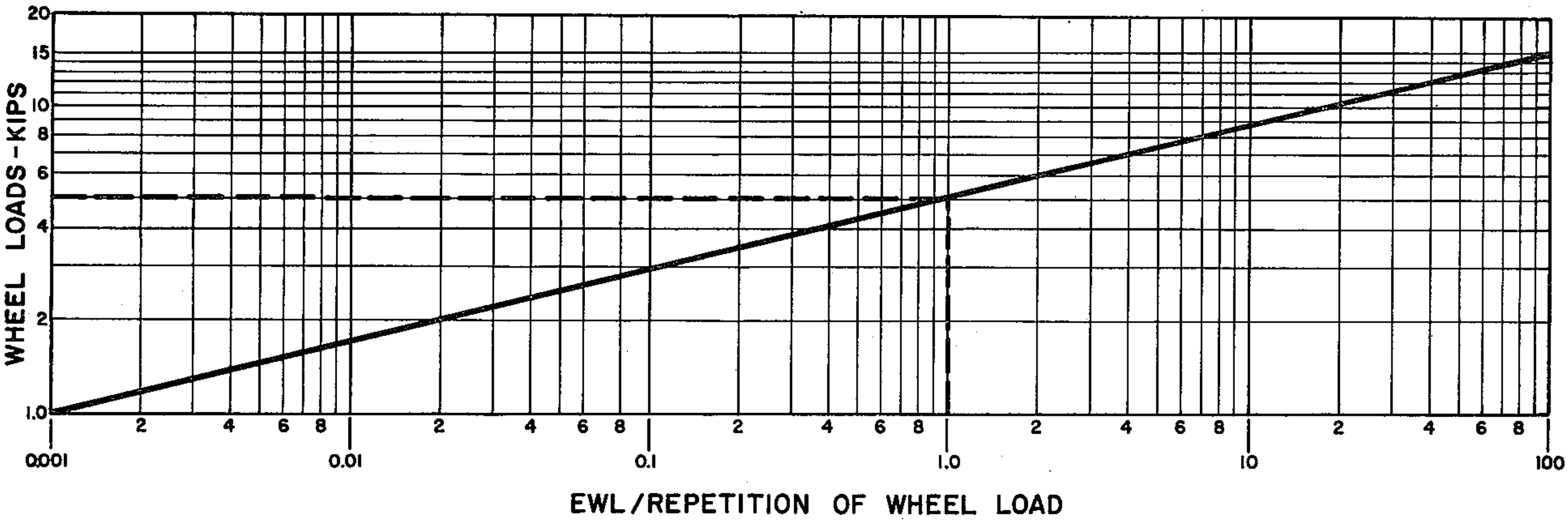
EWL Constants for Dual-tired Commercial Vehicles

	Annual Design EWL per Vehicle per Day	
Type of vehicle	State Highways	City Streets and County Roads
2-axle truck	280	200
3-axle truck	930	690
4-axle truck	1320	1070
5-axle truck	3190	1700
6-axle truck	1950	1050

Figure A-1

CONVERSION CHART

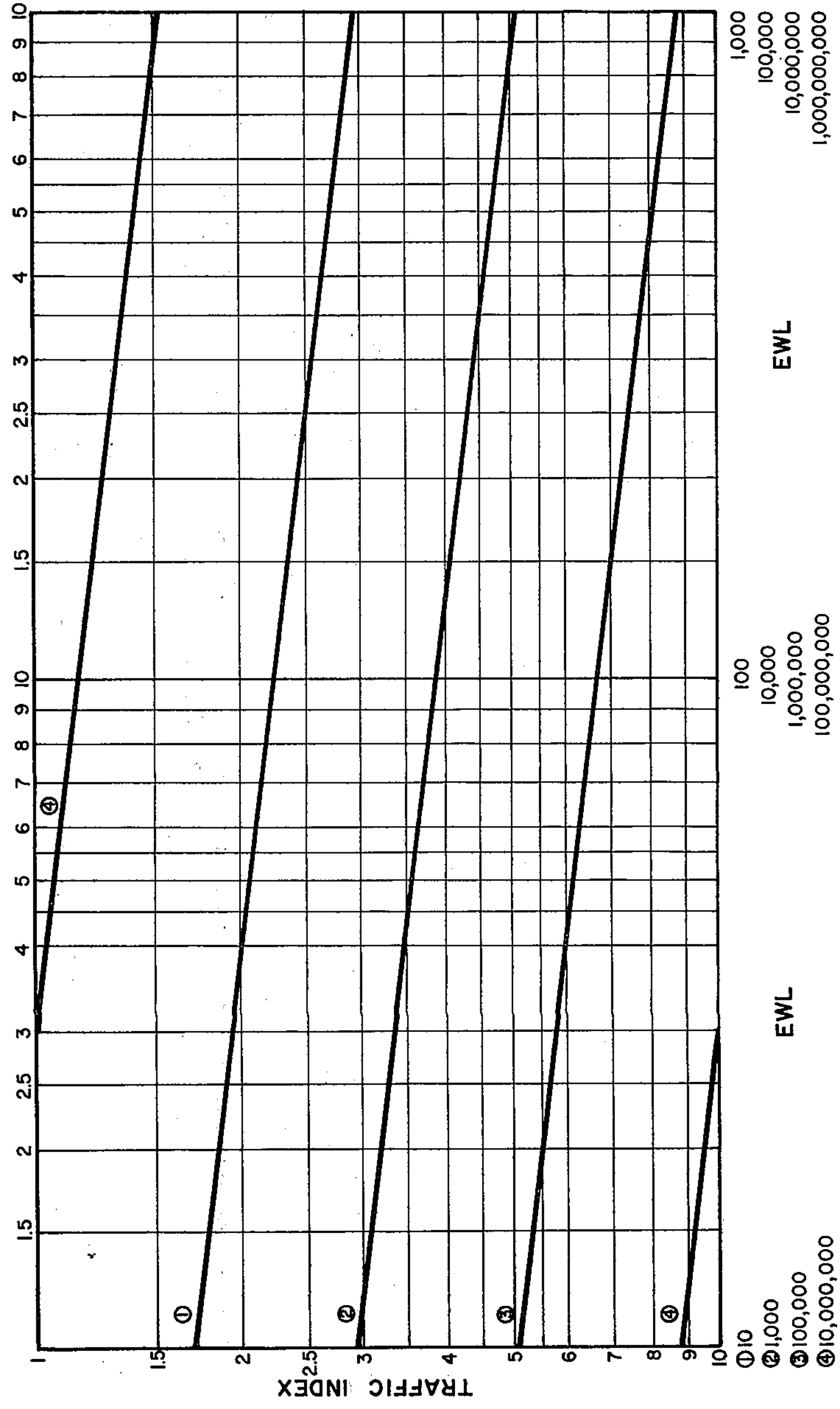
AVERAGE WHEEL LOAD TO EQUIVALENT 5,000 LB. WHEEL LOADS



SOLUTION OF: $EWL = (\frac{W}{5})^{4.2}$

Figure A-2

CONVERSION CHART
EWL to TI



Solution of $TI = 6.7\left(\frac{EWL}{10^6}\right)^{.119}$

APPENDIX B

TEST METHOD FOR CALIFORNIA BEARING RATIO

APPARATUS REQUIRED

A cylindrical mold six inches (6") in diameter and eight inches (8") high. The mold is to be fitted with a detachable base plate, a piston or plunger five inches (5") high and of slightly less diameter than the inside diameter of the mold for compacting the specimen, and a round penetration piston with an end area of three (3) square inches.

A perforated plate with an adjustable stem and a ten (10) pound weight.

A testing machine, calibrated hydraulic press or other static loading apparatus of at least 60,000 pounds capacity.

A scale or balance of twenty (20) kilograms capacity sensitive to one (1.0) gram.

A dial or other suitable gauge for measuring the penetration of the three inch (3") area piston.

A dial or gauge mounted in a tripod for measuring the specimen during the soaking period.

A suitable water tank or vat for immersing the specimen during the soaking period.

A twelve and one-half (12-1/2) pound round surcharge weight for confining the top of the specimen during penetration.

A suitable drying oven with forced ventilation.

Miscellaneous equipment including a depth gauge graduated in hundredths of an inch, mixing bowl, spoons, spatulas, graduates, brushes, etc.

PREPARATION OF SAMPLE

A representative sample of sufficient size for the tests (usually 20 to 40 pounds) shall be accurately quartered. The sample to be tested shall be separated into sizes by screening on 3/4", 3/8" and No. 4 sieves, and the percentage passing each sieve determined, if a grading analysis has not been made. Particles retained on the 3/4" sieve shall not be used in the material to be tested. This procedure will result in three sizes of material for the test, namely 3/4" to 3/8", 3/8" to No. 4, and passing the No. 4. The three sizes should be kept separate.

The tests, insofar as possible, shall be made on a representative sample of the material proposed for use in the work.

STATIC LOAD COMPACTION TEST PROCEDURE

A test sample of approximately four thousand (4,000) grams or such amount which will result in a compacted specimen four to six inches (4" to 6") high, having the same gradation as the minus 3/4" fraction of the original sample, shall be weighed to an accuracy of five (5) grams and placed in the mixing bowl. In the event the maximum dry weight per cubic foot and the optimum moisture content have not been previously determined, three to six identical samples shall be prepared.

Samples need not be completely dried out, but should contain less than the moisture content for the test. If not completely dry, the moisture content should be determined so that the actual dry weight of material used and its actual moisture content will be available before adding additional water.

The sample shall be mixed with the amount of water (optimum moisture content) producing the maximum dry weight per cubic foot obtainable under the static load compaction test herein specified. If the optimum moisture content has not been previously determined, the additional samples referred to above shall be moistened and compacted at varying moisture contents so that a range well on each side of optimum is covered and the optimum moisture content determined.

After thoroughly mixing the material with water, it shall be lightly tamped into the tared mold and then compacted to its maximum density under a load of two thousand (2,000) pounds per square inch. In applying the load between one thousand (1,000) pounds and two thousand (2,000) pounds, the head of the testing machine or hydraulic press shall be operated at a rate of approximately five hundredths of an inch (0.05") per minute. The static load of two thousand (2,000) pounds shall be maintained on the specimen for one (1) minute and then gradually released during a period of twenty (20) seconds.

The mold shall then be removed from the testing machine or hydraulic press and the height of the compacted specimen measured, with a depth gauge, to the nearest hundredth of an inch. The dry weight per cubic foot of the specimen shall be calculated from the height and diameter of the specimen and its dry weight.

BEARING RATIO TEST PROCEDURE (RELATIVE BEARING VALUE)

A seven inch (7") diameter filter paper shall then be placed on top of the mold containing the above-described compacted specimen, and the base plate removed from the bottom and fastened to the mold over the filter paper. The mold shall then be turned over and the specimen recompacted under a load of two thousand (2,000) pounds per square inch, applied as specified for the "Static Load Compaction Test" on preceding page.

After being soaked as hereinafter provided under "Expansion Test", the specimen shall be tested for penetration in the following manner:

The specimen shall be placed in the testing machine and tested by penetrating with the small piston (end area of three square inches). Before starting the penetration test, the surcharge weight shall first be placed on the top of the specimen. The piston shall then be set on the center of the compacted specimen and firmly seated by applying an initial load of ten (10) pounds, after which the dial shall be set at zero to measure the penetration of the piston. During the penetration test, the head of the testing machine shall be operated at a rate of five hundredths inch (0.05") per minute and the total load and the load in pounds per square inch shall be recorded at penetrations of 0.1 inch, 0.2 inch, 0.3 inch, 0.4 inch and 0.5 inch.

The bearing ratio (relative bearing value) shall be computed in percentage of the following standard loads for each one-tenth inch (1/10") increment of penetration:

Penetration Inches	Standard Load pounds per square inch
0.1	1,000
0.2	1,500
0.3	1,900
0.4	2,300
0.5	2,600

Unless otherwise specified, the bearing ratio of a material shall be considered as the bearing ratio at 0.1" penetration.

EXPANSION TEST PROCEDURE

The height of the recompacted specimen described under "Bearing Ratio Test Procedure" shall be recorded to check the height and the dry weight per cubic foot of the specimen as originally compacted as well as for use in determining the expansion percentage.

A six-inch (6") diameter filter paper shall then be placed on the recompacted specimen, followed by the perforated plate and then the ten (10) pound weight. The gauge and tripod assembly shall next be set on the mold and the stem on the perforated plate adjusted and locked to a zero gauge reading. After removing the gauge, the mold assembly shall be placed in the tank and water poured in the top of the mold. The water level in the tank and in the mold shall, at all times, be kept between one inch (1") above and two inches (2") below the top of the mold.

The specimen shall be soaked for four days or if the material becomes fully saturated and all expansion ceases before this time, a shorter soaking period will be permitted. The expansion shall be measured each day with the gauge and tripod assembly and recorded to the nearest one-thousandth of an inch. The percentage of expansion shall be calculated on the basis of the height of the recompacted specimen before soaking.

After the soaking period, the specimen shall be removed from the tank, the ten (10) pound weight removed, and with the perforated plate held firmly in place, the mold shall be tipped up to allow the free water to drain off for a period of one (1) minute. Care must be taken to prevent disturbing the surface of the sample and to avoid vibration which will cause saturated material, particularly sands and silts, to become "quick". The ten (10) pound weight, perforated plate and filter paper shall then be removed, after which the specimen, contained in the mold, shall be weighed to determine the moisture content of the material after the soaking period.

After weighing, the soaked specimen shall be tested for penetration as above described under "Bearing Ratio Test".

MOISTURE CONTENT PROCEDURE

After the penetration test has been completed on the soaked specimen as above specified, a sample shall be taken from the top of the specimen to a depth of one inch (1"), weighed and dried to constant weight at 100 to 104 degrees centigrade.

This moisture content shall be recorded together with the moisture content for maximum compaction and that of the total specimen after soaking.

Design Procedure:

The first requirement of the design is to convert the known CBR values to equivalent R-values by means of the nomograph delineated in Figure B-1. The nomograph is not applicable for a material possessing all three of the following characteristics: (1) Less than 75% passing a #4 sieve, (2) more than 8% passing the #200 sieve, and (3) a product of the plasticity index and percent passing the #200 sieve is greater than 72. The R-values for materials possessing all three of the preceding characteristics should be determined in accordance with the R-value test procedures as outlined in Test Method No. Calif. 301F.

After the equivalent R-values for the various structural section components have been determined, the structural section design method should follow the procedures previously outlined in the text.

Example: Conversion of CBR to an equivalent R-value:

Given: Material characteristics
Subgrade CBR = 4 Swell = 4%
Percent passing #200 sieve = 67
Percent passing #4 sieve = 100
Plastic Index = 10

a. Check subgrade material characteristics against the limitations specified for acceptable use on Nomograph (Figure B-1).

Limitation 1 - Less than 75% passing #4 sieve
Sample has 100% passing #4 sieve

Limitation 2 - More than 8% passing #200 sieve
Sample has 67% passing #200 sieve

Limitation 3 - Product of the Plastic Index and percent passing #200 sieve greater than 72.
Sample = 10 x 67 = 670, which is greater than 72.

The material does not meet Limitation #1, therefore, the Nomograph is applicable since the criteria for rejection of the Nomograph requires conformance to all three Limitations.

b. Nomograph Procedure.

Refer to the Nomograph (Figure B-1) for the following example procedure. The corresponding steps (1, 2, 3, 4, & 5) and the straight edge projections denoted by dashed lines are indicated on the Nomograph.

(1) Locate CBR value of 4 on Scale A.

(2) Locate on Scale B the numerical value determined from the formula:

$$\frac{\%\ \text{pass}\ \#200\ \text{sieve}}{\%\ \text{pass}\ \#4\ \ \text{sieve}} \times 100 = \frac{67}{100} \times 100 = 67$$

(3) By means of a straight-edge project a line through points located on Scales A and B to Scale C the Turning Scale.

(4) Locate on Scale D the CBR expansion value determined from the CBR test which in our example is 4%.

(5) By means of a straight edge project a line through the points located on Scales C and D to Scale E.

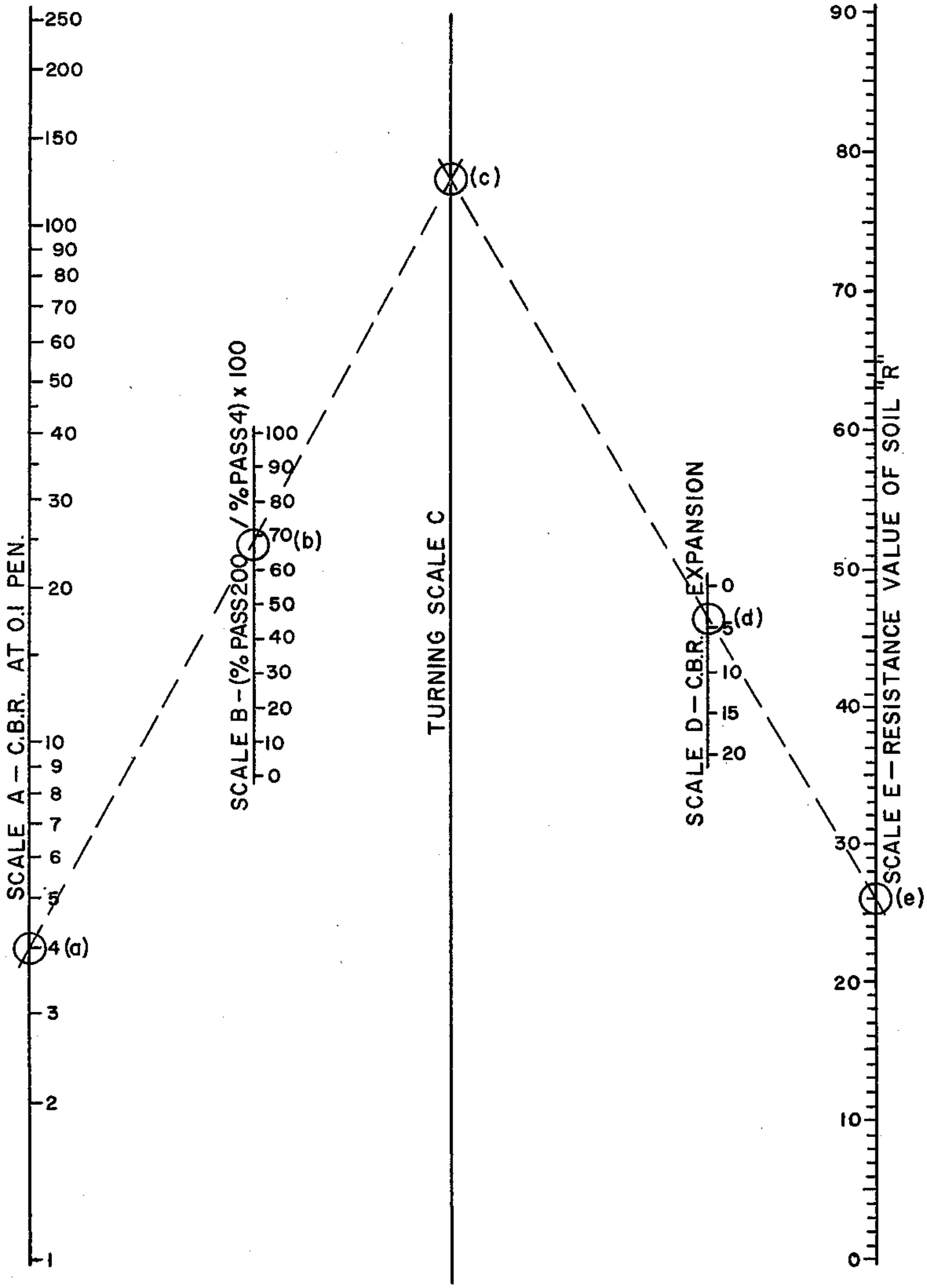
(6) Read the equivalent R-value (Resistance Value) on Scale E which for our example is 26 (for subgrade).

(7) Repeat steps 1 through 6 to determine equivalent R-values from CBR values for other structural section components.

(Base, Subbase)

(8) After the determination of the R-values for the base, subbase and subgrade materials, the structural design method should follow the procedures previously outlined in the text.

Figure B-1



RESISTANCE VALUE OF SOIL "R" ESTIMATED FROM C.B.R. DATA

This chart not applicable for any material possessing all three of the following characteristics: (1) Less than 75% passing #4 sieve, (2) more than 8% passing #200 sieve and (3) a product of the plasticity index and percent passing #200 sieve greater than 72.

FLEXIBLE PAVEMENT

structural section design guide for california cities and counties